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IMPROVEMENT OF THE WAR-GAMING CAPABILITY (WAGCAP)

Final Report

DIVWAG Technical Manual

Volume III

UNITED STATES ARMY COMBAT DEVELOPMENTS COMMAND

Combat Developments Research Office

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This volume contains the technical description of the DIVWAG model. The manual presents the DIVWAG design concept, describes the military reality simulated, and provides the rationale for the modeling approach. The sources or derivation of parameters, equations, and submodels are included.

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Event Scheduling			
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WAGCAP
IMPROVEMENT OF THE WAR GAMING CAPABILITY

VOLUME III - DIVWAG TECHNICAL MANUAL

PREPARED FOR

USACDC COMBAT SYSTEMS GROUP

UNDER CONTRACT DAAG 11-70-C-0875

IN RESPONSE TO USACDC WORK DIRECTIVE 2-72,
IMPROVEMENT OF THE WAR GAMING CAPABILITY (WAGCAP),
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FIGURES

FIGURES (continued)

FIGURES (continued)

DIVWAG TECHNICAL MANUAL

CHAPTER 1

INTRODUCTION

1. PURPOSE. The purpose of this volume of the WAGCAP documentation series is to describe the DIVWAG system models that simulate the activities of military units and the interaction of these units with other units, the environment, and the situations represented in the system.

2. BACKGROUND. The DIVWAG system was developed in the course of execution of two consecutive study efforts. The first of these study efforts, entitled: Development of a Division War Game Model (DIVWAG), resulted in a war game model which was capable of simulating the interaction of division forces in modern land combat but which required improvements in order to be used acceptably as a force planning tool. The second effort, entitled: Improvement of the War Gaming Capability (WAGCAP), undertook the improvements desired, trained government personnel in the operation of the model, and conducted a gaming test of the improved model. Tasking established for the DIVWAG study project and carried forward into the WAGCAP project required the development of a computer-assisted war game model capable of:

a. Evaluating forces composed of maneuver units and their associated combat support and combat service support.

b. Producing detailed quantitative data for use in comparing the effectiveness of the forces.

c. Examining at least 14 continuous days of combat, if required.

d. Producing the evaluation data required for analysis 60 days after the evaluation of the force commences.

e. Addressing high and mid intensity conflict (nuclear and conventional war).

f. Addressing the surveillance and target acquisition functions and providing quantitative data that will permit evaluation of the contribution that varying sensor mixes provide to force effectiveness.

g. Addressing firepower to provide quantitative data that will permit evaluation of varying mixes of firepower means and demonstrate their contribution to total force effectiveness.

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h. Providing a means for evaluating the effects of varying degrees of aerial, ground, and firepower mobility; and assessing the effect of mixes of mobility means on total force effectiveness.

i. Analyzing the command, control, and communications functions. This may be accomplished subjectively if the state-of-the-art or the additional model complexity precludes meeting the responsiveness requirements (2d above). If practical, decision and communication delay times may be inserted by a control element outside of the computer.

j. Producing loss, expenditure, and consumption data for use in evaluating the capabilities of supply and transportation systems using varying supply rates as constraints on consumption or expenditure.

3. SCOPE:

a. This technical manual contains the documentation of major models within the DIVWAG system. In addition to introductory material, Chapter 1 contains a general description of the DIVWAG system design, emphasizing the logical sequencing of events within that portion of the system that actually conducts the game simulation, the Period Processor. Successive chapters deal with the modeling of various functional areas within the Period Processor.

b. Chapter 2 documents a set of basic system models which have a general impact throughout the DIVWAG simulation. These include models to represent the natural environment (terrain and weather), to describe obstacles and facilities, and to represent military units within the DIVWAG system. Parametric representation of weather is accomplished through the use of weather zones overlayed on the terrain of interest, each zone being described in terms of atmospheric conditions which are updated hourly. The representation of elementary terrain characteristics is accomplished through the establishment of 2-kilometer square grid cells of the area of operation. Each grid cell is coded for terrain roughness and vegetation, forestation, and soil trafficability; and the geographical area of interest is further overlayed with a dominant masking function. The impact of terrain on military actions has been significantly improved within the DIVWAG system by the incorporation of terrain elevation and by the use of terrain elevation and the dominant masking function to establish line of sight conditions. The DIVWAG Model treats man-made obstacles and facilities as well as significant terrain features within the context of a larger barrier line or zone. This treatment permits a reasonable consideration of the effects of such factors on military movement. The representation of units within the DIVWAG system has been significantly improved in that the gamer has a great deal of flexibility in representing the units being considered, both in terms of the positioning of assets within the area occupied by a unit and in the composition of units through a task organization structure that is under gamer control. Chapter 2 also discusses the DIVWAG system approach to approximating unit boundaries, areas of responsibility, and the trace of the forward edge of the battle area (FEBA).

c. Chapter 3 presents the Intelligence and Control Model of the DIVWAG system. The model treats the target acquisition and information gathering process, exchange of information between units and echelons, and elementary decision-making based on this information within an integrated intelligence and control model. Significant features include the ability to play a broad range of target sensing devices and an interconnection with selected firepower models, permitting fires to be automatically brought to bear on acquired targets.

d. Chapters 4, 5, 6, and 11 contain documentation of the major models within the DIVWAG system used to simulate the application of firepower. The DIVWAG Ground Combat Model simulates the interactions between opposing ground maneuver units. The Ground Combat Model, discussed in Chapter 4, has been totally revised with the intention of improving such basic aspects as target acquisition, weapon representation, and casualty assessment. The delivery and assessment of effects of nonnuclear area fires is simulated by the Area Fire/TACFIRE Model, documented in Chapter 5. A capability for automated scheduling of nonnuclear fires is also discussed in Chapter 5. The delivery, assessment of immediate effects, and assessment of residual or delayed effects of nuclear weapons is treated within the Nuclear Assessment Model, documented in Chapter 11. The Air Ground Engagement Model, documented at Chapter 6, treats the attack of ground targets by aircraft either in response to direct gamer orders or in response to targets generated by the Intelligence and Control Model. All actions from the receipt of strike order through the return of aircraft to their home base are simulated within the model.

e. Chapters 7, 8, and 10 treat various aspects of mobility within the DIVWAG system. The Movement Model, documented at Chapter 7, treats the ground movement of units except when such movement is under control of the Ground Combat or Combat Service Support Models. The Movement Model will frequently interact with the Engineer Model, documented at Chapter 8. In its current stage of development, the Engineer Model simulates the construction of obstacles as part of a gamer prescribed barrier plan and the breaching or removal of barriers and construction of movement facilities (bridges, fords) in response either to gamer orders or to requests generated by the Movement Model. The Movement Model also treats simple air movement; i.e., movements not associated with an airmobile operation. Airmobile operations are treated within the Airmobile Model, discussed in Chapter 10. This model treats an entire airmobile movement, from the allocation and routing of aircraft to a pickup point through loading of the airmobile force; movement to a landing zone with associated in-flight attrition and suppression of air defense weapons by escort aircraft, where appropriate; offloading; and release of the aircraft for further assignment. Simulation of forward area refuel and rearm points is also accomplished within the Airmobile Model.

f. Chapter 9 documents the Combat Service Support Model. This model simulates the replacement of personnel and major items as well as the resupply of consumables (Classes I, III, IV, and V).

4. DIVWAG SYSTEM DESIGN:

a. Processors. The total DIVWAG system contains five closely interrelated but distinctly separate computerized processors, each of which plays a unique part in the game cycle. The five processors are:

- Constant Data Input Processor
- Orders Input Processor
- Period Processor
- Period Output Processor
- Analysis Output Processor

The function of each processor is discussed briefly below.

(1) Constant Data Input Processor. The Constant Data Input Processor is composed of a group of special purpose data load programs that read source data from cards, convert the data to the form required by the Period Processor, and load the processed data onto each of the appropriate DIVWAG data files. There are 55 such data files maintained on one or, if needed, two magnetic disks. Record and backup copies of the contents of the disk are maintained on magnetic tape. Each load program fills one or more data files with the constant data required for a specific submodel or group of submodels. A complete description of the Constant Data Input Processor, the individual load programs, and constant data requirements is contained in Volume VI, DIVWAG Data Requirements Definition.

(2) Orders Input Processor:

(a) The Orders Input Processor provides the communication link from the gaming group to the Period Processor and the DIVWAG submodels within that processor. The Orders Input Processor accepts gamer orders prepared in DIVWAG Source Language (DSL). All units within DIVWAG are classified as either resolution or nonresolution units. Resolution units are those units that can be given specific orders. Nonresolution units are constituent elements of resolution units and higher echelon units that are not discretely addressed. The use of nonresolution units permits explicit recording of the status of all force elements of interest. Gamer orders are translated into machine executable instructions that provide the basis for guiding the sequence of events within a game period.

(b) A set of machine executable instructions, derived from the gamer orders, is created for each resolution unit given orders during the period. Additional flexibility is provided by a branching capability, which

enables alternative order sequences to be executed as a result of gamer-prescribed conditions. The lack of a program for a resolution unit causes an implied stay order for the entire period.

(c) Similar instructions are also created for each ground combat engagement. These programs specify the units to be engaged; the conditions upon which the engagement is to terminate; and, based upon the outcome, the orders to be performed by each engaged unit after the engagement has terminated.

(d) This processor reads source cards, compiles the DSL orders and places the instructions on a disk file. A copy of this file is retained on magnetic tape for record and backup. A more comprehensive discussion of the use and operation of this processor is contained in Volume IV, DIVWAG Users Manual.

(3) Period Processor:

(a) The central element of the DIVWAG system is the Period Processor. This processor contains the mathematical models, data maintenance routines, and event scheduling and execution logic required to simulate the military activities portrayed in DIVWAG. The Period Processor is the principal subject of this volume. Paragraph 5 of this chapter provides an overview of the processor, and the remaining chapters discuss each of the major submodels within the processor.

(b) The Period Processor accepts as input data files from the Constant Data Input Processor and the instructions from the Orders Input Processor. It then executes the prescribed sequence of events for each resolution unit for the duration of the game period. It checks the stated branching conditionals and alters the sequence accordingly. Each of the submodels is executed as required to process:

- Intelligence, control, and communication events, including air reconnaissance flights
- Fire mission assignment events
- Artillery and missile area fire events
- Ground combat events
- Attack helicopter and close air support events
- Movement events including ground movement, simple air flights, and complex airmobile operations

- Engineering required to implement a barrier plan or to clear barriers

- Resupply of consumables and replacement of personnel and major items.

In addition to those major events specified by DSL orders, numerous automatic events are generated within the Period Processor to effect the routine orders not required to be explicitly prescribed by the gamers.

(4) Period Output Processor. Upon completion of the game period, a set of post-period reports is produced to be used as guidance in preparing the orders for the following period. These reports include:

- Intelligence Reports

- Force Status, Activity, and Loss Reports

- Barrier Reports.

(5) Analysis Output Processor. The Analysis Output Processor is composed of two sets of computer programs, Information Retrieval and Display System (RADS) and Statistical Tabulations (STATAB).

(a) IRADS. The function of the IRADS programs is to extract data from the history tapes produced by the Period Processor and to array the data in proper form for the STATAB programs. Additionally, the IRADS programs have the capability of printing a formatted copy of all or selected records from the history tapes.

(b) STATAB. The purpose of the STATAB program is to perform the numerical operations of the nonparametric statistical analysis of the game output. The details of the statistical analysis techniques are described in Volume II, Analytical Methodologies. The STATAB program embraces all statistical problems in a multiple rank ordering process. Game data are organized by functional area, and effectiveness indicators are defined to support the measures of effectiveness that pertain to each functional area. A one-way analysis of variance (ANOVA) is applied to game data arrayed by unit or system type for each effectiveness indicator. This ANOVA utilizes the Kruskal-Wallis one-way ANOVA and the Mann-Whitney U-Test (one-way) to acquire rank ordering of performance by unit type and system type. After acquiring unit/system ranks for each effectiveness indicator, effectiveness indicators applicable to each function of land combat are assembled into sets; and their attendant ranks within sets are gathered into an array, which is subjected to the Friedman two-way ANOVA and the Mann-Whitney two-way test. This sequential application of one-way ANOVA for all indicators followed by a two-way ANOVA results in a final rank ordering of units and systems for each functional area of combat.

b. Integrated DIVWAG System:

(1) Figure 1-1 illustrates the flow of information through the DIVWAG system from processor to processor and to and from the war game staff. Figure 1-2 depicts the data communication links among processors from a physical (hardware) standpoint.

(2) The data preparation group assembles and prepares the raw data to be used by the Constant Data Input Processor. The data are entered on specially designed coding sheets from ADP cards keypunched and verified. The Constant Data Input Processor reads the data cards, accomplishes any necessary calculations, and loads the input data onto the required data files for the start of the first period. After a set of data files is loaded, the contents of all DIVWAG data files loaded up to that point in time can be written onto a dump tape using a special purpose dump program. The dump tapes thus generated serve as backup for the disk files and enable an earlier set of files to be consulted, if necessary, by loading the contents of a dump tape back onto the disk using a special purpose load program.

(3) The game period cycle is initiated when the gaming staff prepares the set of orders for the first game period. The orders written in DSL are keypunched and verified. These cards serve as the input for the Orders Input Processor which creates the absolutized orders programs and loads them on the orders file where they can be executed by the Period Processor. After the orders file has been loaded, the dump program is again used to produce a dump tape. From this stage on, dump tapes contain both the up-to-date DIVWAG data file and the current orders file.

(4) The data files and the DSL order programs for the period having been loaded, the Period Processor is executed to simulate the period of battle. Output tapes are created for use in the analysis phase, and the dynamic data files are continually updated.

(5) At the completion of each period, the Period Output Processor generates postperiod reports which are used by the gamers to initiate succeeding periods of play. At least one dump tape is created to retain a record of the files at that point in the game and to enable the files to be reloaded if necessary. This cycle continues until the game is completed.

(6) The Analysis Output Processor IRADS programs read the history tapes, print formatted listing of history tape records at the user's option, extract, and properly array data for the STATAB programs. The STATAB programs accomplish the required statistical calculations.

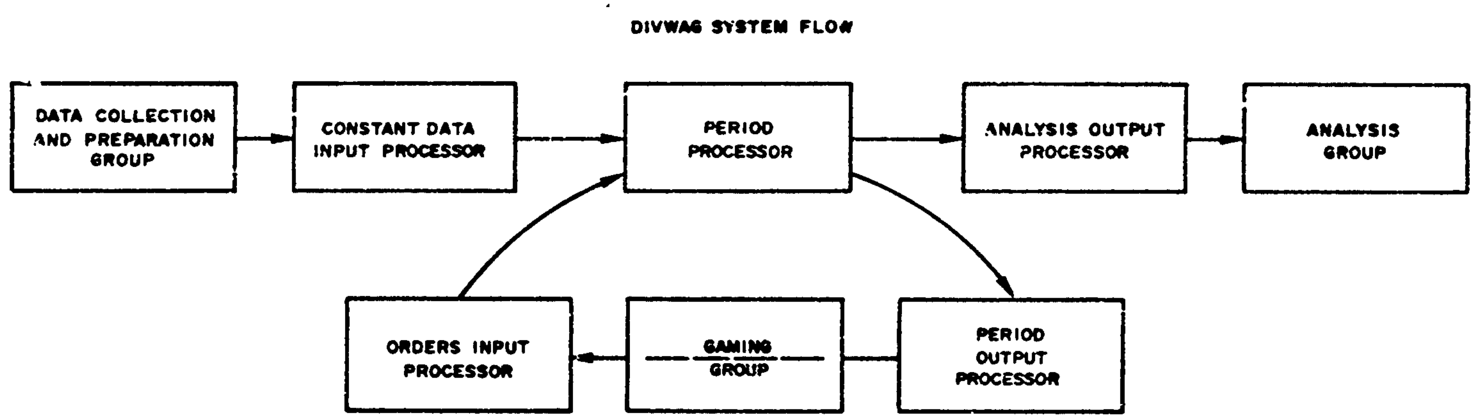

Figure 1-1. DIVWAG System Flow

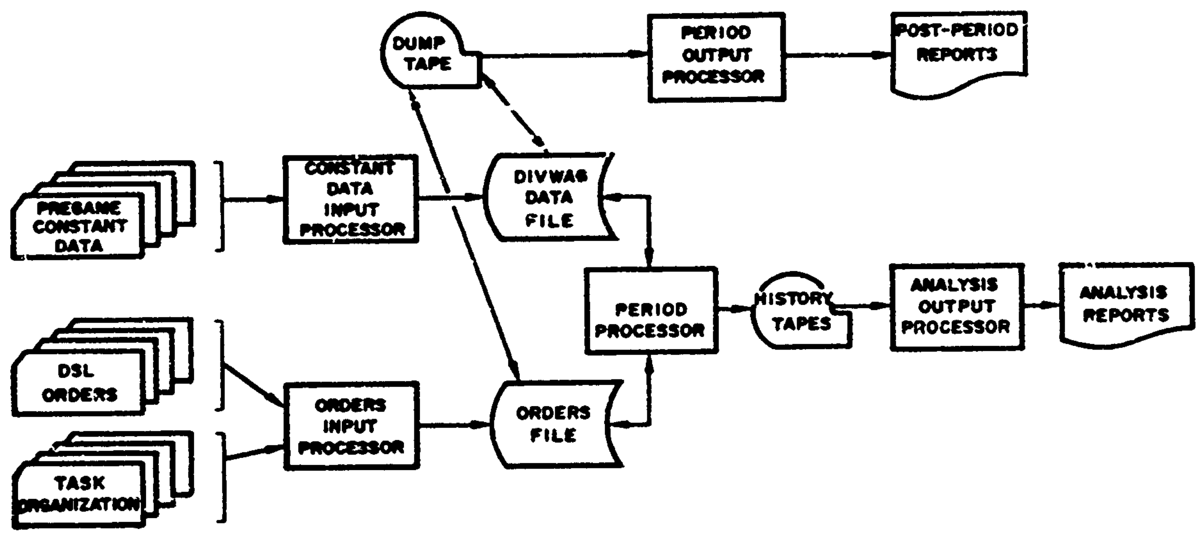

Figure 1-2. Inter-Processor Data Flow

5. PERIOD PROCESSOR:

a. General. This paragraph presents an overview of the Period Processor describing the basic flow and processing sequence required within one period of game activity. An appreciation of this flow, and especially of the logic of event sequencing used throughout the system, is prerequisite to an understanding of the descriptions of the individual system models contained in the following chapters.

b. Period Initialization:

(1) Initial Operation. The initial operation of each period is generally the loading of the period orders file and the DIVWAG data files using the load program. This step may be omitted if the disk storage device is known to contain the desired data and orders programs. Next, the linkages between the orders file and the Period Processor are initialized. This initialization loads the unit and battle directory tables into core, enabling the Period Processor to locate, upon the orders file, the appropriate order program for any desired unit or named battle. The initialization also sets the period starting time, sets the length of period, and identifies the period as a start of game or as a subsequent period. Following orders initialization, several frequently accessed constant data arrays are constructed in Chapter 2 common and rolled out to a scratch file from which they can be reloaded as required. The remaining initialization process is different for the first period than for subsequent periods.

(2) First Period. The weather zone boundaries and intelligence and control tables are taken from the appropriate data file and placed into core. The unit identification location and unit type designator tables are constructed in Chapter 2 common. The event time table is initialized. Several dynamic data files are created. Terrain masking parameters are established for all resolution units. The first events for all resolution units are initi :ed.

(3) Subsequent Periods. Both Chapter 1 and Chapter 2 common are reloaded with their former contents, carried on the data file between periods. If this is a midperiod restart due to an unanticipated interruption, the output tapes are repositioned to the appropriate resumption point.

(4) Every Period. Finally, the approximate battlefield orientation, FEBA trace, and brigade and division boundaries and areas of responsibility are determined. These calculations are updated automatically throughout the period at a frequency dependent upon the amount of activity simulated.

c. The Event Cycle:

(1) Basic Event Sequencing Logic. The DIVWAG Period Processor operates with a basic event sequencing logic. Within this logic, there are two parts to most of the models of military activity, a delta time computation

for the activity and an activity assessment computation. As illustrated in Figure 1-3, an activity is thus dealt with in two distinct steps within the flow of gamed activity. In the first step, the delta time computation portion of the activity model is exercised to determine the time at which the activity is to be assessed. In the second step, the actual assessment of the results of the activity is accomplished. Since accomplishment of an activity will generally take some finite amount of time, there is generally a period of simulated time between the point (time T) at which the activity initiates and the point in time (time T + ΔT) at which assessment of the results of the activity is scheduled. During this intervening period of time, other activity assessments and delta time computations for the same or other units will generally be accomplished.

(2) Event Sequencing within the Period Processor:

(a) Control of Event Sequencing. The principal executive routine within the Period Processor controls the logical flow of event sequencing, using the event time table and the game time clock as its basic sources of information. Each entry in the event time tables contains the scheduled game time of an event and an indication of the type of event scheduled. The event time table is composed of two segments. The first segment contains event scheduling information for the pending DSL-ordered event for each resolution unit. The second segment of the event time table contains event scheduling information for up to 3000 automatically scheduled events. A cycle through the executive routine is made for every event, once the event time table has been initialized. The cycle begins with a search of the entire event time table to determine which pending event is scheduled to be processed at the earliest game time. Once the next scheduled event has been identified, the game time clock is incremented to the scheduled time, the event type is determined, and the appropriate routine for assessment of the results of the event is called. Upon completion of the assessment of results of an event, the next ordered event for the involved unit is scheduled if the event just assessed was a DSL-ordered event. The cycle repeats with a search of the event time table for the next event after assessment of an automatically scheduled event or scheduling of the next ordered event. The basic flow of this process is shown in Figure 1-4.

(b) Event Scheduling:

1. DSL Ordered Events. The life cycle of an event resulting from a DSL order begins with a call to a routine, which locates the next order on the orders file for the specified unit and places that order in the unit's Unit Status File record. The appropriate length of time required to perform the event is computed and stored in the Event Time Table. No further processing or updating for that event is performed until it is due to be completed. During the time interval between event scheduling and completion, numerous events will undoubtedly be completed and processed for other units.

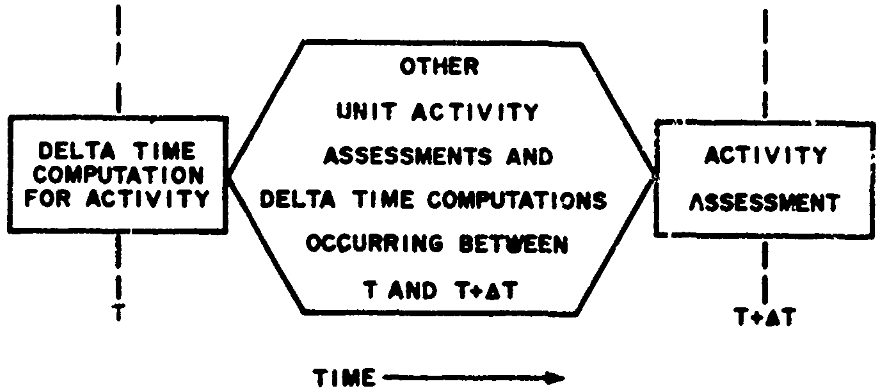

Figure 1-3. Basic Event Sequencing Logic

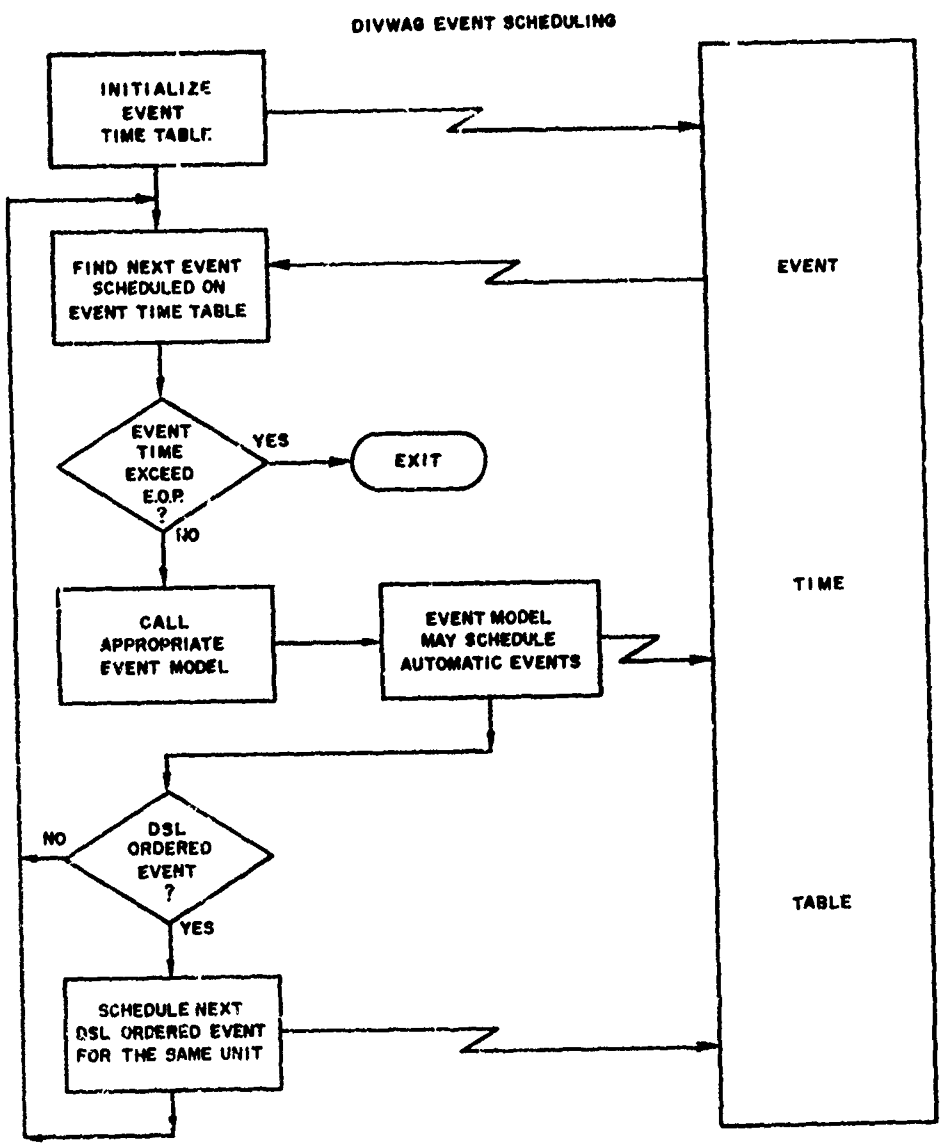

Figure 1-4. Event Scheduling within DIVWAG System

2. Automatic Events. One inherent constraint of the DSL order system described above is the restriction that every resolution unit have one and only one pending event and order at all times. To alleviate this constraint and to reduce the burden of preparing routine orders from the gaming group, an automatic event system was implemented. This system automatically generates, schedules, and processes routine events within the Period Processor, thus leaving DSL for the higher level, command type orders. Such automatic events are generated by the Combat Service Support, Movement, and Intelligence and Control Models and pass through the TACFIRE, Air Ground Engagement, Engineer, and Airmobile Models. In general, automatic events are of the following types:

- Sensing reports
- Fire support requests
- Information flow
- Intelligence processing
- Communications
- Requests for close air and direct aerial fire support
- Artillery mission assignment and scheduling
- Air mission assignment and scheduling
- Airmobile operation scheduling
- Resupply and replacement actions
- Engineer task assignment and scheduling.

The automatic events are scheduled in response to key situations arising dynamically during the assessment of results of these and other appropriate events.

d. End of Period. Upon normal termination of a period, the event time table is adjusted so that the internal clock can be reset to zero at the beginning of the following period. The contents of Chapter 1 and Chapter 2 common are stored on disk, and two copies of the dump tape are made. Any ground engagements that have not ended are terminated. The Period Output Processor is then called to produce the post-period reports.

e. Restart. An additional insurance feature of the Period Processor is its restart capability. At periodic intervals during the game period, a restart dump is made by saving the contents of common, writing an end of file

mark on the output tape, and dumping the data files and the DSL order file to a tape. In the event of a machine failure between restart dumps, it is only necessary to back up to the time of the last restart dump, load the files, and resume processing. The restart dump interval is specified on a data card with each Period Processor run. In addition, a special restart dump can be initiated by entering the appropriate instructions via the computer console.

CHAPTER 2

BASIC SYSTEM MODELS

1. INTRODUCTION:

a. General. In addition to the various military activity models (discussed in later chapters of this volume), the DIVWAG system contains a group of basic system models each having a distinctive effect on some of the activity models. This chapter discusses the basic system models.

b. Physical Environment. A simulation of military activities must consider the prevalent environmental conditions at the place and time of the activity. For each activity to be simulated, the DIVWAG system uses a parametric approach to model the general characteristics of the terrain and significant natural and man-made features upon the terrain, as discussed in Paragraph 2. Paragraph 3 contains a discussion of the parametric description of weather conditions at the time of simulated activity as used within the DIVWAG system.

c. Military Unit Representation. The means used to represent a unit within a simulation can have a profound impact upon the validity and possible level of resolution of the simulation. Generally, some compromise is reached between the possible extremes of attempting to individually depict every person and item of equipment within the force and consolidating the entire force into one parametrically described entity. Paragraph 4 discusses the representation of a military unit within the DIVWAG system. Paragraph 5 contains a discussion of the means available within the system for organizing groups of units into task organizations to meet varying military requirements within the game.

d. Battlefield Orientation. The military commander will typically use a wide range of control measures to maintain unity of effort within his force. The DIVWAG system approximates several of the elementary control measures available to the commander. These include selected unit boundaries, areas of responsibility, and the trace of the forward edge of the battle area (FEBA). These approximations are discussed in Paragraph 6.

e. Terrain Masking. The effects of terrain masking on the target acquisition and information collection functions are simulated within the model. A terrain elevation data file describing an elevation grid is used to calculate the dominant mask function for each unit gamed. The intervisibility between a unit and a point is determined from the mask function. The procedure for calculating and using the mask function is described in Paragraph 7.

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2. TERRAIN REPRESENTATION:

a. Basic Terrain Characteristics:

(1) The geographic area in which the war game is to be conducted is described by a rectangle, which may be as large as 8,388,000 meters on a side. Within this area, any point can be described to the nearest meter by the use of 14-digit Cartesian coordinates of the form xxxxxxx-yyyyyyy. All locations in the model are defined in terms of a continuous metric grid with the x-axis oriented east-west, the y-axis oriented north-south, and the origin (0000000-0000000) being the extreme southwest corner.

(2) The overall area to be gamed is divided into square subareas or cells (limited to 30,000). Cells of any integer number of meters on a side can be selected, but all cells must be the same size. Terrain characteristics are assumed to be homogeneous for a given cell; therefore, it is advantageous to establish a terrain cell size small enough to approach true homogeneity. On the other hand, larger cell sizes for the same overall area to be gamed enable easier preparation of input data and faster model execution. The overriding consideration to be applied in the selection of a terrain cell size is the requirement for effectively addressing the game objectives. Each terrain cell is described in terms of cover and concealment characteristics and trafficability. This description is provided by three indices for each cell: a roughness and vegetation index; a forest type index; and a trafficability index.

(a) Roughness and Vegetation Index. The roughness and vegetation (RV) index describes a combination of terrain slope variation and non-forest vegetation. The RV indices range from 1 through 9 (unity indicates the best conditions for line of sight and lack of concealment, and 9 indicates the worst conditions). The nine roughness and vegetation categories describe cover and concealment. The categories can be modified to suit the characteristics of a particular area of operations. Examples of the nine roughness and vegetation categories and corresponding values of the RV index are as follows:

1. Flat to gently rolling terrain cultivated with low-growing crops, naturally covered with short grasses, or barren of vegetation. RV index is 1.

2. Flat to gently rolling terrain covered with cultivated tall-growing crops, natural scrub growth, or tall grasses. RV index is 2.

3. Gently rolling to undulating terrain barren of vegetation. RV index is 3.

4. Gently rolling to undulating terrain covered with either cultivated low-growing crops or higher, sparse natural vegetation. RV index is 4.

5. Gently rolling to undulating terrain covered with cultivated tall-growing crops, natural grasses, or scrub growth. RV index is 5.

6. Undulating to broken terrain cultivated with low-growing crops, naturally covered with short grasses, or barren of vegetation. RV index is 6.

7. Undulating to broken terrain covered with cultivated tall-growing crops, natural scrub growth, or tall grasses. RV index is 7.

8. Broken to rough terrain with moderate to dense scrub growth. RV index is 8.

9. Rough terrain with moderate to dense scrub growth. RV index is 9.

(b) Forest Type Index. This general descriptor of forest cover can be changed to fit the specific terrain for a given game; however, any change must consider the tables utilizing the forest type index. One of four forest indices is assigned to each terrain cell in the gaming area. The indices range from 0 for the least cover to 3 for the greatest cover. In areas of deciduous tree growth, the seasonal crown cover should be considered in assigning indices. A sample list of forest types and associated indices is as follows:

1. No extensive stand of trees. Forest (F) type index is 0.

2. Planted stand of trees, such as orchards, or well-maintained coniferous forests of the European type with sparse crown cover. F type index is 1.

3. Naturally-established deciduous or coniferous forests growing under less than ideal conditions with moderate crown cover. F type index is 2.

4. Natural forest of broad leaf trees and heavy undergrowth growing in near ideal conditions with tall trees and dense crown cover. F type index is 3. Currently, DIVWAG differentiates only between unforested (F is 0) and forested (F is 1, 2, and 3) conditions.

(c) Trafficability Index. The trafficability index describes the terrain mobility characteristic of each terrain cell. The system is designed to accommodate a total of 20 trafficability indices. It is not mandatory that all 20 potential indices be used in a given game. In assigning the trafficability index, the user must consider three factors affecting mobility: slope of the terrain, its soil bearing characteristics, and the forest condition.

1. Five basic terrain types have been identified as being representative, although they may be modified as desired for any given game:

- Flat to gently rolling
- Gently rolling to undulating
- Undulating to broken
- Broken to rough
- Rough, mountainous, cut by ravines; flat swamps and marshes; or flooded agricultural areas.

Within each basic type, varying slope gradients may be identified. For example, if gently rolling to undulating terrain is defined as that which varies in elevation from 100 to 200 meters per 1000 meters distance, these variances may be translated into slope or degrees of slope.

2. The soil bearing characteristics of the terrain may vary from good to poor, and this factor must be considered in assigning the index. A relationship between soil and slope should also be recognized, since the poorer the soil bearing characteristics, generally, the greater the effect that slope has on trafficability. For definitions of the current slope and soil trafficability indices, see Figure 2-1.

3. The forest (F) type index assigned to the terrain cell (see Paragraph 2a(b)) also has a direct effect on trafficability and must be considered in assigning the trafficability index.

b. Elevation Grid. The elevation of the terrain is described by the height above sea level (in meters) of each point on the elevation grid. The origin of the grid coincides with the basic terrain origin and extends in the x and y directions a distance that includes the total gaming area. The grid spacing is the same in both the x and y direction. The spacing of the elevation grid is independent of the terrain cell size and should be selected to provide sufficient elevation resolution without excessive data requirements.

c. Use of Terrain Characteristics. Figure 2-2 contains a summarization of the use of terrain characteristics by the major DIVWAG models. The terrain roughness and vegetation and forestation indices are used in combination by the Intelligence and Control Model, the Ground Combat Model, and the Air Ground Engagement Model. In all three cases the indices are used to establish the level of concealment or the masking effect within a terrain cell. The Area Fire/TACFIRE Model uses the forest type index to establish a level of cover from the effects of area fire weapons afforded by local forestation. The Engineer Model uses the trafficability indices to determine rate modifiers to be applied to engineer task performance rates to account for degradation due to terrain characteristics at task sites. The Movement Model uses the

Index	Type Slope	Type Soil	Forest
01	Flat to gently rolling	Coarse-grained, poorly graded sand and silt with clay layer	Forested
02	Flat to gently rolling	Coarse-grained, poorly graded sand and silt with clay layer	Not Forested
03	Flat to gently rolling	Silt over clayey sand and sandy clay	Forested
04	Flat to gently rolling	Silt over clayey sand and sandy clay	Not Forested
05	Gently rolling to undulating	Coarse-grained, poorly graded sand and silt with clay layer	Forested
06	Gently rolling to undulating	Coarse-grained, poorly graded sand and silt with clay layer	Not Forested
07	Gently rolling to undulating	Silt over clayey sand and sandy clay	Forested
08	Gently rolling to undulating	Silt over clayey sand and sandy clay	Not Forested
09	Undulating to broken	Coarse-grained, poorly graded sand and silt with clay layer	Forested
10	Undulating to broken	Coarse-grained, poorly graded sand and silt with clay layer	Not Forested
11	Undulating to broken	Silt over clayey sand and sandy clay	Forested

Figure 2-1. Trafficability Index (continued next page)

Index	Type Slope	Type Soil	Forest
12	Undulating to broken	Silt over clayey sand and sandy clay	Not Forested
13	Broken to rough	Coarse-grained, poorly graded sand and silt with clay layer	Forested
14	Broken to rough	Coarse-grained, poorly graded sand and silt with clay layer	Not Forested
15	Broken to rough	Silt over clayey sand and sandy clay	Forested
16	Broken to rough	Silt over clayey sand and sandy clay	Not Forested
17	Rough terrain	Coarse-grained, poorly graded sand and silt with clay layer	Forested
18	Rough terrain	Coarse-grained, poorly graded sand and silt with clay layer	Not Forested
19	Rough terrain	Silt over clayey sand and sandy clay	Forested
20	Rough terrain	Silt over clayey sand and sandy clay	Not Forested

Figure 2-1. Trafficability Index (concluded)

Model	Terrain Characteristic	Utilization
Intelligence and Control	Elevation	Used to determine line of sight
Ground Combat	Roughness/Vegetation and Forestation	Used to calculate line of sight probability and background reflectance
Area Fire/ TACFIRE	Forestation	Used to establish vulnerability of personnel
Air Ground Engagement	Roughness/Vegetation and Forestation	Used to compute degradation of air defense weapon effectiveness
Engineer	Trafficability	Used to compute degradation of engineer task performance rates
Movement	Roughness/Vegetation	Used to establish average speed of units moving on road
	Trafficability	Used to establish average speed of units moving cross country
Combat Service Support	Roughness/Vegetation	Used to establish average speed of resupply convoys
Airmobile	Elevation	Used to determine line of sight to air defense weapons

Figure 2-2. Use of Terrain Description with DIVWAG System

roughness and vegetation and the trafficability indices as parameters for determining the movement rates for units and vehicles, using the RV index for road movement and the trafficability for cross country movement. The Combat Service Support Model also uses the roughness and vegetation index to determine vehicle road movement rates. The elevation grid is used to calculate dominant mask functions which are used by the Intelligence and Control Model to determine the existence of line of sight between sensors and unit and by the Airmobile Model to determine the existence of line of sight between aircraft and air defense weapons. Details of these applications are found in the chapters dealing with the appropriate DIVWAG military activity models.

d. Terrain-Barrier Relations. The relations of terrain features, forestation, and man-made facilities which affect significantly (hinder or facilitate) force mobility are considered in the Engineer Model in the context of barriers and facilities.

(1) In a division-level war game with battalions as maneuver units, individual obstacles of a local nature, unless they are an integral part of a larger barrier line/zone, or are in rough, mountainous terrain, generally have negligible delaying effect on mobility and are of a nuisance value only.

(2) Natural and man-made features having appreciable effect on mobility (e.g., mountains, dense forests, unfordable streams, minefields, and bridges) are integrated into barrier lines of significant extent. Any feature which tends to reduce mobility is treated as a barrier, and any feature which tends to enhance mobility is treated as a facility.

(3) Barrier lines are represented by a sequence of connected line segments. Each segment is considered homogeneous and is identified by a six-character mnemonic. The first three characters are alphabetic and identify the type of segment; i.e., forest, river, antitank minefield, and fixed bridge. The other three characters are numeric and are unique within that type segment.

(4) Facilities are assigned unique segments in the barrier line. These segments are given finite lengths to facilitate their intersection by the movement paths of the Movement Model.

(5) In general, barriers may be breached by facilities, through engineer tasks. For example, a river barrier segment may be breached by constructing a bridge, a raft/ferry, or in some cases a ford.

(6) Some barrier segments which are unsuitable for facilities are designated as unbreachable; for example, cliffs and rivers through marshlands or with steep rocky banks.

(7) Gamers define barrier lines during pregame activities as part of their barrier and facility planning. Lines may be modified between game periods.

(8) Barrier segment definitions include endpoint coordinates. The Engineer Model computes task magnitudes which are dependent on barrier lengths. The model also computes task rates and total task times, the latter are used for assessing mobility delays.

3. WEATHER:

a. Representation of Weather Conditions:

(1) The geographical area subdivided into terrain cells is also subdivided into weather zones to reflect weather conditions. A maximum of nine rectangular weather zones may be defined by specifying the coordinates of each corner of the zone. The zones should be established so that each zone has distinct weather parameters. Homogeneity of weather across the zone is desired, since the model assumes consistency of weather parameters within a weather zone.

(2) Within each weather zone, weather is described for each hour of game time in terms of the following parameters:

(a) Temperature (degrees, Fahrenheit).

(b) Precipitation (none, light, or heavy).

(c) Fog (yes or no).

(d) Cloud cover (percent).

(e) Wind speed (knots).

(f) Wind direction (azimuth in degrees).

(g) Relative humidity (percent).

(h) Visibility index (1-9; 1 worst, 9 best).

(3) The first seven of the eight parameters above are established in the pregame phase with parameters describing moon conditions (quarter, moonrise, and moonset) and sun conditions (time for beginning morning nautical twilight (BMNT), end evening nautical twilight (EENT), sunrise and sunset). In the pregame phase, the user has the option of entering actual or assumed weather condition parameters for a given time period. (See Volume VI, DIVWAG Data Requirements Definition.)

(4) The visibility index, which is used extensively in the Air Ground Engagement, Intelligence and Control, and Ground Combat Models, is determined from the cloud cover, precipitation and fog parameters, and the times of sunset, sunrise, moonrise, and moonset. The visibility index is determined by a table searching procedure by the weather-generating model, if the user

chooses the probabilistic approach. The entire procedure is described in detail in Volume VI, DIVWAG Data Requirements Definition. The visibility index table used in the system is shown in Figure 2-3.

b. Use of Weather Parameters. Weather parameters are used in the Ground Combat, Air Ground Engagement, Movement, Intelligence and Control, and Engineer Models. The parameters are generally used in representing the impact of weather conditions affecting local visibility or mobility. Details of these applications are found in the chapters documenting the appropriate DIVWAG military activity models.

4. UNIT REPRESENTATION:

a. General. The DIVWAG system allows a great deal of flexibility in representing military units and groupings of units by allowing the gamer to vary the level of resolution of a unit or group of units during the course of a game. Keys to this flexibility are the DIVWAG Unit Status File, the concept of resolution and nonresolution units, and the set of DSL TRANSFER-type orders with their associated TRANSFER-implementing models.

b. Unit Status File. The Unit Status File is a dynamic game data file that contains the current (in game time) status description of all units in the game. The file contains space for 1000 records, permitting the play of up to 1000 military units. As each activity-simulating model within the DIVWAG system is executed, the Unit Status File records of units involved in the activity are updated to show current unit status. Most data entries on the Unit Status File can be grouped into five categories:

(1) Unit identification entries used within the system. The most important item in this category is the UID. This is the name of the unit used by the gamer in issuing orders to the unit. Data within each file record used to keep track of organizational structure also fall into this category.

(2) Unit strength entries. These entries contain the current personnel strength and amounts on hand of equipment and materiel for the unit.

(3) Unit geometry entries. These entries are used to locate a unit on the battlefield, define the area physically occupied by the unit, and establish the unit's distribution of personnel and materiel within that area.

(4) Unit activity entries. These entries are used to indicate the unit's current activity and, in many cases, the objective of that activity. They are reset each time the unit receives a new order.

(5) System linkages. These entries on the unit status file are used to maintain linkages to several other system files that may contain records pertinent to a specific unit.

Cloud Cover / Time of Day	No Precipitation				Light Precipitation		Heavy Precipitation
	$0 \leq C_i \leq 40$	$40 < C_i \leq 60$	$60 < C_i \leq 80$	$C_i > 80$	$60 \leq C_i < 80$	$C_i > 80$	$C_i > 80$
BMNT to Sunrise	8	7	6	5	4	4	4
Sunrise to Sunset	9	8	8	8	8	6	4
Sunset to EENT	8	7	6	5	4	4	4
No Moon	2	2	2	2	1	1	1
Quarter Moon	3	3	3	3	3	2	2
Half Moon	4	4	4	3	3	2	2
Full Moon	4	4	4	3	3	2	2

NOTE: Maximum V during ground fog is 2.

Figure 2-3. Visibility Index

c. Resolution and Nonresolution Units:

(1) To achieve an ability to change military organizational structures and the level of unit resolution within the course of a game, the DIVWAG system uses a concept of resolution and nonresolution units. The war game is actually conducted only with the resolution units. Only resolution units are treated by the various system models of military activity; only resolution units are treated as physically occupying some space within the battle area; orders can be given directly only to resolution units; events can be scheduled only for resolution units; attrition, consumption, losses, resupply, and replacements are directly computed only for resolution units. Nonresolution units are used for bookkeeping purposes. The flexibility in this system is achieved by allowing the gamer to combine several resolution units into one larger unit, thus lowering the degree of unit resolution; or to decompose a resolution unit into smaller subunits, thus raising the degree of unit resolution, at any point in the course of the game.

(2) Figure 2-4 illustrates the use of resolution and nonresolution units in the context of a military organizational structure. In this figure, a brigade organization is depicted at the battalion level of resolution. While the brigade is thus resolved, the gamer actually plays the three battalions and the brigade headquarters company. Thus, although the 17 units depicted all have records on the Unit Status File, only the four resolution units are directly available to the gamer orders or to the activity-simulating models of the system. The figure also illustrates one of the various ways in which the gamer could reorganize the nine component maneuver companies of two armor battalions and one mechanized infantry battalion during the course of a game.

(3) By issuing the proper sequence of orders, the gamer could combine the three battalions and the brigade headquarters company depicted in Figure 2-4 into the brigade unit. At that point, his organization would be at the brigade level of resolution; orders could be issued only to the brigade as a whole; and the brigade as a whole would be treated by the system models. By issuing another sequence of orders, any one or all of the battalions could be further decomposed into its component companies. If, for example, the third battalion were thus decomposed, the battalion would be at the company level of resolution; the gamer would issue his orders to each company; each company would be simulated within the system's models; and the battalion itself would be a nonresolution unit.

(4) At the current stage of model development, the ability to vary unit resolution must be used with some care. Although it is possible to vary the resolution level of units at will, excessively large units may invalidate the results of certain of the military activity models. Thus, it is not recommended that units that are expected to be involved in an exchange of firepower during the course of a game period be placed at any lower detail than battalion level resolution during that period.

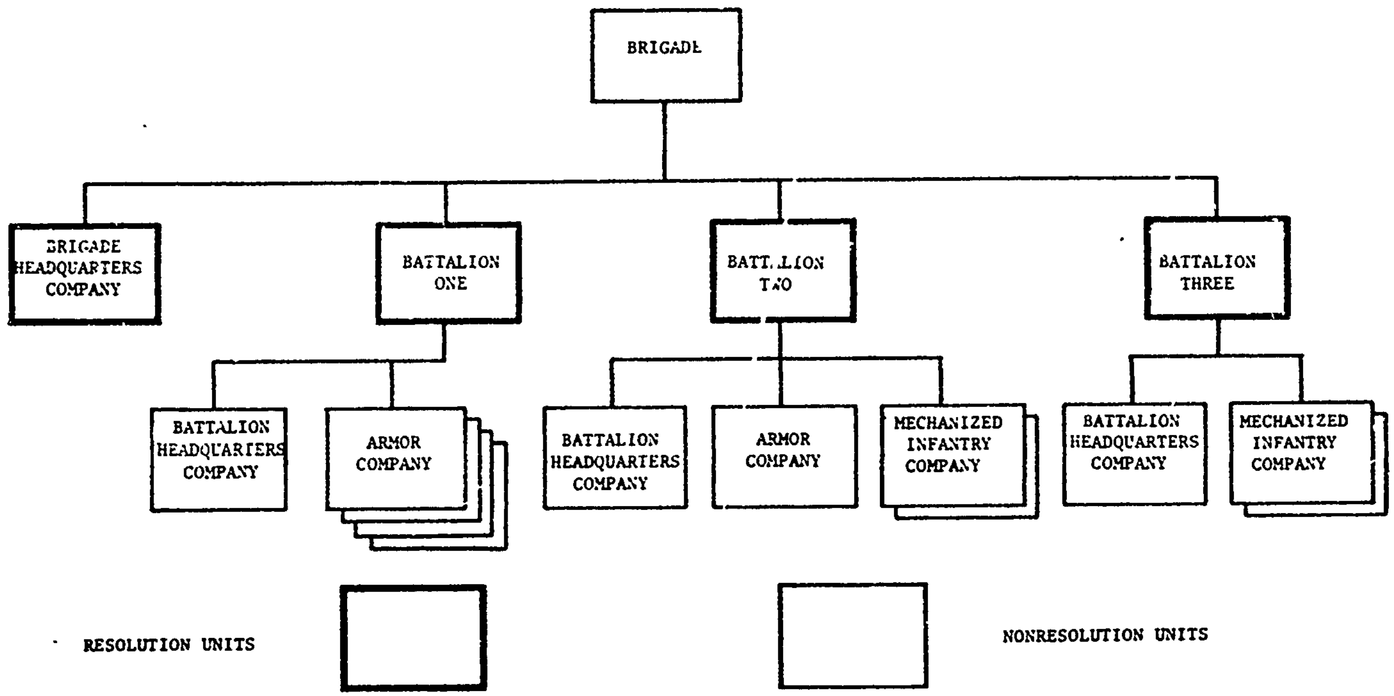


Figure 2-4. Brigade Organization at Battalion Level Resolution

d. Representation of Resolution Units:

(1) General. As previously stated, only resolution units are represented within the DIVWAG models of military activity. Each resolution unit is represented by a rectangle centered around the unit's location as illustrated in Figure 2-5. Associated with the unit rectangle is a size, an orientation, and a distribution of personnel and equipment within the rectangle. Size and orientation are adjusted at the beginning of each gamer-ordered event. Distribution of equipment and personnel is updated when required for Area Fire/TACFIRE Model assessments or for the Ground Combat Model.

(2) Unit Size. The width and depth of the rectangle representing a resolution unit are functions of the type unit and its current activity. These sizes are specified by the gaming staff as part of the game data base (see Volume VI, DIVWAG Data Requirements Definition) for each of the following activities:

- Staying (inactive)
- Moving (cross country)
- Firing (artillery units)
- Attacking (in the Ground Combat Model and while advancing to the attack)
- Defending (in the Ground Combat Model and in a defensive position)
- Withdrawing (in the Ground Combat Model and when disengaged)
- Performing engineer activities.

Units moving on roads are assigned a fixed width of 25 meters and a depth, or column length, of 110 meters per vehicle. Units attacking, defending, or withdrawing can be ordered to assume nonstandard dimensions by appropriate DSL orders.

(3) Unit Orientation. The front of a moving unit faces the objective of the move. The front of a stationary unit is oriented toward the enemy in that the front edge of a stationary unit is parallel to a line approximating the FEBA. (Calculation of this line is documented in Paragraph 6.) Within the model, orientation is entered in the unit's Unit Status File record as measured counterclockwise from the positive x axis of the terrain coordinate system.

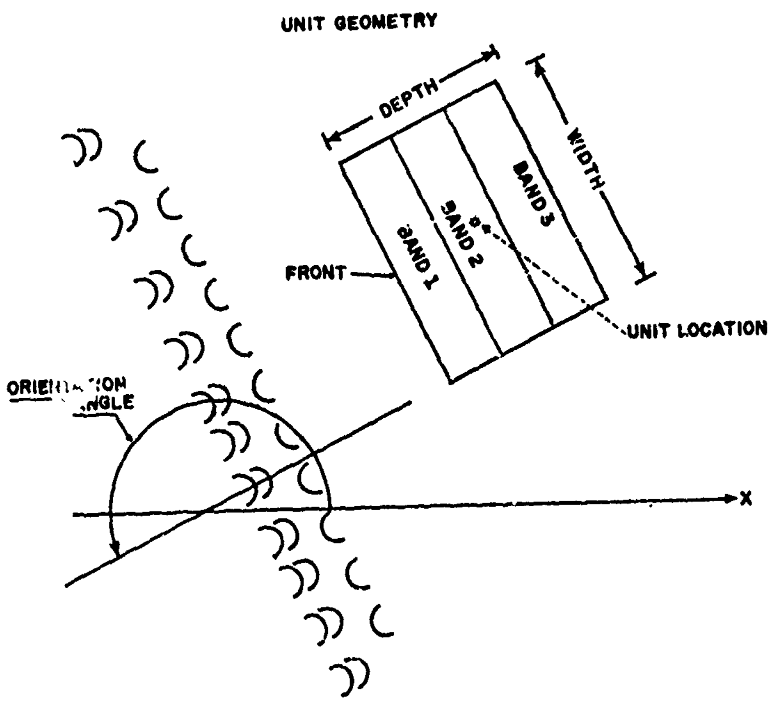


Figure 2-5. Unit Geometry

(4) Distribution of Personnel and Equipment. The DIVWAG Model assumes a uniform distribution within from one to four bands of equal size within the unit for area fire assessment and ground combat calculations. The number of bands and distributions within bands are determined by the type unit and its current activity, the same factors used to determine unit size. A unit's size is not altered by a loss of equipment or personnel. These data must be specified within the game data base (see Volume VI, DIVWAG Data Requirements Definition).

5. TASK ORGANIZATION:

a. General. Within the DIVWAG system, changes to the task organization of a force and the level of resolution of the units within a force are accomplished by the set of Transfer routines. The Transfer routines generally operate upon the records of the Unit Status File and the Authorized Strength File. The Authorized Strength File contains the numbers of personnel and items of equipment authorized for each unit having a record on the Unit Status File. The entries of a Unit Status File generally used by the Transfer routines are unit identification entries, unit strength entries, and the unit's location.

b. Basic Units. Prior to the initiation of gaming, the game constant data base is loaded with Tables of Organization and Equipment (TOE) to be used in the course of a game. Within the TOE are defined basic units. These basic units are the building blocks with which the force is structured. All units within the game are composed of groupings of these basic units. The essential limitations imposed on the gamer are that the force must always contain the exact number of basic units specified within the TOE and that the basic unit is the greatest level of unit resolution possible; that is, the basic unit cannot be decomposed into component subunits.

c. Subordinate List. Every Unit Status File record has space allocated for a list of up to ten subordinate or component units. On the sample organization of Figure 2-4, the subordinate list of the brigade unit contains the brigade headquarters company and the three battalions. The subordinate list of each battalion unit contains the battalion headquarters company and the maneuver companies, with the first battalion having five, the second battalion having four, and the third battalion having three subordinate or component units listed. The subordinate lists of the brigade and battalion headquarters and maneuver companies would be empty in this example. Each Unit Status File record also has a superior pointer. In the example, the battalion headquarters company and maneuver companies would have the appropriate battalions indicated as their superior unit; the brigade headquarters company and battalions would have the brigade unit identified as their superior; and the brigade, in this abbreviated example, would have no superior unit indicated. (Within an actual game, the brigade would probably be contained within the subordinate list of a division and would show the division as its superior.)

d. Unit Status File for Resolution Units. The DIVWAG system uses the unit location entries of a Unit Status File record to discriminate between resolution and nonresolution units. The x and y map coordinates of all nonresolution units are set to zero. Thus, resolution units are those with nonzero coordinates. Unit geometry entries in the Unit Status File record of resolution units are set based on the type unit and current activity, as described in Paragraph 4d. Unit activity entries of the Unit Status File generally are used only for resolution units, since activity is actually simulated only for the resolution unit. The unit strength entries of a resolution unit's Unit Status File record contain the current number of personnel and items of equipment within the unit.

e. Unit Status File for Nonresolution Units. The x and y map coordinates of a nonresolution unit's Unit Status File record are set to zero. Other unit geometry and unit activity entries of a nonresolution unit's Unit Status File record are not generally used. The unit strength entries on the Unit Status File record are used only for those nonresolution units that are subordinates or components of resolution units. In this case, the component Unit Status File record contains the percentage of personnel or of each item of equipment contained within the superior unit actually associated with the component. A basic result of this approach is that casualties assessed against a resolution unit are indirectly assessed against component units in proportion to the percentage of the superior unit's strength that was drawn from the component.

f. Authorized Strength File. The Authorized Strength File contains a record for each unit appearing within the Unit Status File. Contents of the Authorized Strength File are the numbers of personnel and items of equipment authorized for that unit. A unit's authorized strength file record generally contains the sum of the records of the unit's subordinates. If the unit has been specified as a basic unit, its Authorized Strength File record contains the strength authorized for that type basic unit plus strengths of subordinates, if any. While the situation would not be expected to occur during the normal course of a game, a unit that is not a basic type unit and that has no subordinates would have its Authorized Strength File zeroed within the system.

g. Basic Transfer Routines:

(1) Subordinate and Authorization Changes. The Unit Status File list of subordinates, superior pointer, and the Authorized Strength File are changed in response to the DSL order ASSUME CONTROL OF. When a resolution unit, U_1, receives the order to assume control of a second resolution unit, U_2, the following basic steps are accomplished by the DIVWAG system:

(a) The subordinate list of unit U_1 is checked. If U_2 is already on the list, the order is ignored. If U_1 already has 10 subordinates, a diagnostic message is printed, and the order is rejected.

(b) Unit U_2 is removed from the subordinate list of the unit currently specified as its superior, unit U_3.

(c) Contents of the Authorized Strength File record for unit U_2 are subtracted from the Authorized Strength record of unit U_3, from the Authorized Strength record of unit U_3's superior, and so on up the chain of all superior units.

(d) Unit U_2 is added to the subordinate list of unit U_1, and unit U_1 is specified as the superior unit of unit U_2.

(e) The contents of the Authorized Strength File for unit U_2 are added to the authorized strength of unit U_1, to the authorized strength of unit U_1's superior, and so on up the new chain of superior units.

(2) Increasing Detail of Unit Resolution. The level of detail of unit resolution is increased in response to the DSL order DETACH. The order DETACH does not break command relationships but merely creates a resolution unit. When a resolution unit, U_1, receives an order to detach unit U_2, the following basic steps are accomplished by the DIVWAG system.

(a) A check is made to determine if U_2 is currently subordinate to U_1. If not, the order is rejected and an informative message printed.

(b) A check is made to determine if unit U_2 is already a resolution unit. If it is, the order is ignored.

(c) Unit U_2 is made a resolution unit. It is given the same coordinates as unit U_1 and its current number of personnel and of each item of equipment is set by multiplying the percentages contained in the Unit Status File record of U_2 by the actual strengths in the Unit Status File record of unit U_1.

(d) Unit strength entries of unit U_1 are reduced by the amounts put into the unit strength entries of unit U_2.

(e) If U_2 was the last nonresolution subordinate of U_1, and if U_1 was not specified as a basic unit, then unit U_1 has become a nonresolution unit, and its location is set to zero.

(f) If unit U_1 has other nonresolution subordinates, unit strength entries of these subordinates are adjusted to reflect their current percentage of unit U_1. The adjustment is accomplished by Equation 2-1.

$$F_{NEW} = f_{OLD} / (1 - f_{OUT}) \qquad (2\text{-}1)$$

where:

f_{NEW} = adjusted percentage of superior unit's holdings

f_{OLD} = previous percentage of superior unit's holdings

f_{OUT} = percentage of superior unit's holdings taken out with unit U_2.

(g) An indicator is set so that on return to the main system executive routine the orders file will be queried for orders for unit U_2.

(3) Decreasing Detail of Unit Resolution. The level of detail of unit resolution is decreased in response to the DSL order JOIN. When a resolution unit, U_2, receives an order to join its superior unit, U_1, the following basic steps are accomplished within the DIVWAG system.

(a) Unit U_2 is made a nonresolution unit. Its location is set to zero, and its unit strength entries are added to those of unit U_1. (If U_1 was a nonresolution unit, its location is inherited from U_2; and its unit strength entries are set from U_2 rather than added to.)

(b) Unit strength entries for unit U_2 are set to the percentage of unit strength entries of U_1 just contributed by U_2.

(c) If unit U_1 has other nonresolution component units, unit strength entries of these units are adjusted to reflect their percentage of the holdings of unit U_1 by the equation:

$$f_{NEW} = f_{OLD} \cdot (1 - f_{IN}) \qquad (2\text{-}2)$$

where:

f_{NEW} = adjusted percentage of superior unit's holdings

f_{OLD} = previous percentage of superior unit's holdings

f_{IN} = percentage of superior unit's holdings contributed by unit U_2.

(d) If the superior unit were a nonresolution unit prior to this action, it becomes a resolution unit; and an indicator is set so that on return to the main system executive routine the orders file will be queried for orders for unit U_1.

(4) Changing Unit Activity Entries. One subset of the unit activity entries in the Unit Status File can be changed by the Transfer routines. This subset of entries is designed to permit the player to specify supporting mission assignments for units. As currently implemented, these entries are used to specify, for use by the Area Fire/TACFIRE Model, supporting assignments for artillery units (direct support, reinforcing, general support, or general support/reinforcing). In response to the DSL order ASSIGNMENT IS, followed by appropriate modifiers, given to a resolution unit, the old supporting mission entries will be replaced with those specified in the order.

(5) Interrelations of Transfer Routines. Certain of the Transfer routines generate automatic calls to each other as follows:

(a) If a unit U_1 is given an order to assume control of unit U_2, and unit U_2 is not a resolution unit, an order will be generated to the current superior of U_2 (assuming it is not U_1) to detach the unit U_2 before the ASSUME CONTROL OF order is carried out.

(b) If an order is given to unit U_2 to join unit U_1, and U_2 is not subordinate to U_1, then an order will automatically be generated for U_1 to assume control of unit U_2 before the JOIN order is carried out. Note that this ASSUME CONTROL OF order will not generate an automatic DETACH order because unit U_2 must have been a resolution unit to receive the original JOIN order.

h. Task Organization at Start of Game. The Unit Status File and Authorized Strength File are initially established at the start of the first game period in response to a set of specialized Task Organization input data, submitted with the DSL orders for the first game period. With this input the gamer establishes the names he will use to refer to each unit during the course of the game, the organizational structure he will use to start the game, specification of resolution levels, and initial locations of the resolution units. The initial organization processor verifies that the force uses all basic units authorized and treats an attempt to load more or fewer basic units than specified within the force TOE as a destructive error, preventing any game play until this criterion is satisfied.

6. BATTLEFIELD ORIENTATION:

a. Slope of the Battlefield. The slope of the battlefield is a geometric descriptor of the relative positions and general orientations of forces used for numerous calculations within the Intelligence and Control and Air Ground Engagement Models. It is developed by considering a geometric center of each force, which is determined by averaging the coordinates of all resolution units of the force. These center points are illustrated in Figure 2-6 as the points (AVGBX, AVGBY) and (AVGRX, AVGRY). The slope of the line connecting these points is defined as the slope of the battlefield.

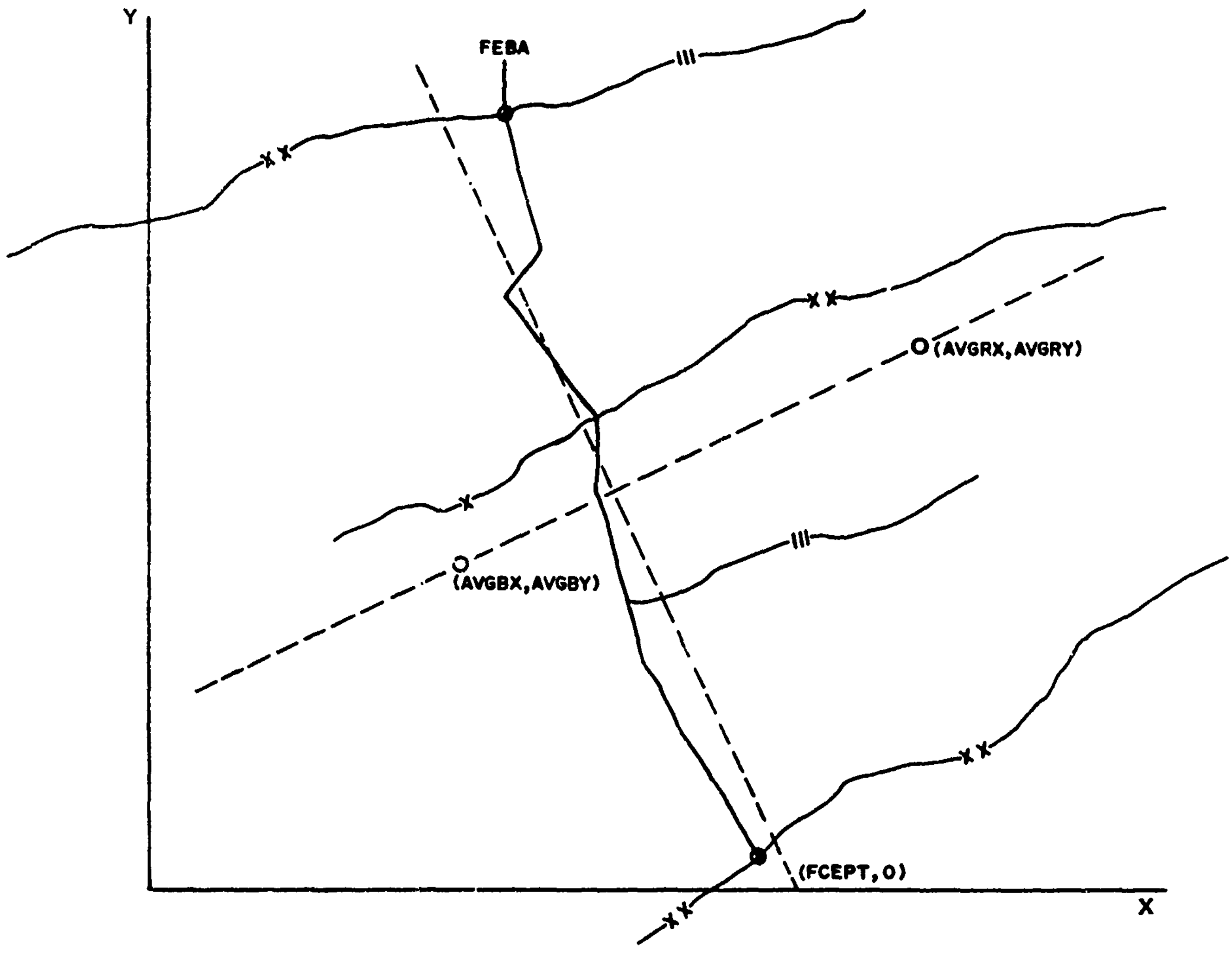


Figure 2-6. Battlefield Orientation

b. FEBA Approximation. A straight line approximating the FEBA is derived in the following manner. The intersection points of the x axis with two lines perpendicular to the battlefield slope and passing through the center of the foremost unit of each force identify the approximate front line of the Blue and Red forces respectively. The midpoint between those two intersection points is the x intercept of the FEBA (FCEPT). Within DIVWAG, the FEBA is approximated by a line perpendicular to the battlefield slope and passing through the point (FCEPT, 0). That line is described by Equation 2-3.

$$x = \text{FCEPT} - y\ (\text{SLOPE}) \qquad (2\text{-}3)$$

This approximation is used for the decision process in the Intelligence and Control Model in cases when greater accuracy is not required.

c. Front Line Units:

(1) A table of front line maneuver battalions, brigades, and regiments is maintained. The table contains a list of all Blue maneuver battalions with center coordinates within D meters of the center coordinates of a Red maneuver battalion where D is the proximity cutoff distance. Similarly, it contains a list of Red maneuver battalions within D meters of a Blue maneuver battalion (center to center). The distance D is automatically adjusted so that no more than 12 maneuver battalions on either force (or a total of 24) qualify as front line battalions and at least six battalions on at least one side qualify as front line battalions. The list is ordered from west to east along the FEBA. The brigades and regiments that are superior to the battalions on the front line lists are inserted on the lists of front line brigades and regiments. These lists are also ordered from west to east along the FEBA.

(2) This table is used by the Intelligence and Control Model to regulate communication and dissemination of intelligence, by the Area Fire/TACFIRE and Air Ground Engagement Models to locate targets relative to front line units, and by the Combat Service Support Model to assign supply priorities.

d. Unit Boundaries and Areas of Responsibility. The boundaries and areas of responsibility are periodically updated and stored on each unit's status record. All boundary lines are assumed to be parallel to the battlefield slope and are defined by their intersection points with the y axis.

(1) Front Line Battalions. Boundaries are calculated for each battalion on the front line maneuver battalion list described in Paragraph 6c above. The boundaries are described by lines parallel to the battlefield slope and midway between the closest points of each pair of adjacent battalions as illustrated in Figure 2-7. The outermost boundary lines for the end battalion (BN_1 and BN_6) are placed at a distance outside the outermost edge

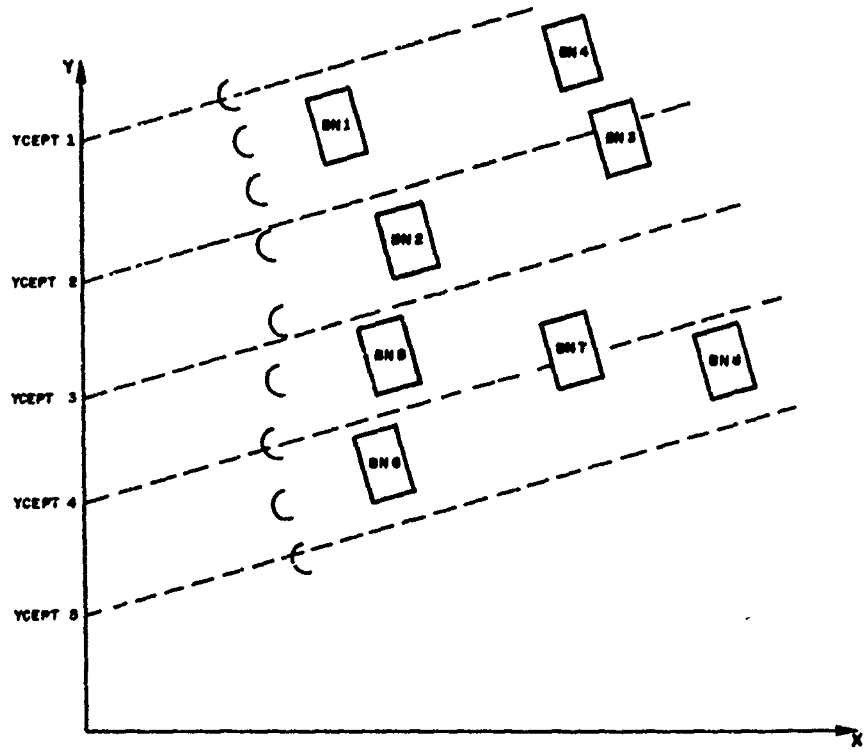


Figure 2-7. Unit Boundaries

equal to the distance the inner boundary is from the innermost edge. The boundary lines for the front line battalions shown in Figure 2-7 are defined by the following YCEPT values:

Battalion	Lower Boundary	Upper Boundary
BN_1	$YCEPT_2$	$YCEPT_1$
BN_2	$YCEPT_3$	$YCEPT_2$
BN_5	$YCEPT_4$	$YCEPT_3$
BN_6	$YCEPT_5$	$YCEPT_4$

(2) Front Line Brigades and Regiments. The boundary lines for each brigade and regiment on the front line lists are set to coincide with the outermost boundary lines of all subordinate maneuver battalions on the front line battalion lists. In the example in Figure 2-7, the brigade superior to battalions BN_1 and BN_2 would be bounded by $YCEPT_3$ and $YCEPT_1$.

(3) Direct Support Artillery Units and Reserve Battaions. The areas of responsibility for battalions in reserve and artillery in direct support of front line brigades and regiments are set to coincide with extensions of the boundaries of the brigade or regiment supported. In Figure 2-7, if BN_4 is an artillery unit in direct support of a brigade consisting of BN_1, BN_2, and BN_3, the area of responsibility of BN_3 and BN_4 is defined by $YCEPT_3$ and $YCEPT_1$.

(4) Division. The division boundary is defined by the outermost boundaries of all subordinate front line brigades or regiments. In Figure 2-7, the division boundary is defined by $YCEPT_5$ and $YCEPT_1$.

(5) Use. The boundary lines are projected into enemy terrain and are used throughout the Intelligence and Control Model to define the areas of responsibility of all maneuver units. The Area Fire/TACFIRE Model uses the division boundaries to assign targets to the appropriate division artillery. These boundaries also provide the groundowrk for the automatic internal control of engineer activity.

e. Update Cycle. The battlefield orientation and unit boundaries are calculated at the beginning of each game period and updated after every 50 movement events (move segments and Ground Combat Model increments.)

7. TERRAIN MASKING:

a. Mask Function:

(1) The mask function is calculated at the start of game for all resolution units and is updated for moving units at the completion of each model move segment. A unit's mask function consists of a 24 by 2 array contained on its Unit Status File. The array holds the range (R) and vertical

angle (α) to the dominant mask feature for every 15° horizontal interval around the center of the unit. Figure 2-8 illustrates the values of R and α for a single 15° interval.

(2) The dominant mask feature is defined as that point at least 1000 and not more than 15000 meters along a radial line from the center of the unit for which the angle, α , is the greatest. The trial range is decreased in 1000 meter steps, beginning at 15000 meters. The dominant mask selection process is performed for all values of the horizontal angle, β , where $\beta = 0°$, 15°, 30°, 45°, ..., 345° measured counterclockwise from the positive x axis. The graphic representation of a mask function is depicted in Figure 2-9.

b. Line of Sight. The determination of line of sight between a unit and a point β' is determined from the unit's mask function and the range and vertical and horizontal angles from the center of the unit to the point in the following manner.

(1) The horizontal radial angle from the center of the unit to the point, β', is measured counterclockwise from the positive x axis. This angle lies between β_i and β_{i+1} of the unit's mask function. The range, R', and vertical angle, α', to the dominant mask feature along a radial angle β' are determined by interpolating between R_i and R_{i+1} and between α_i and α_{i+1} respectively.

(2) Line of sight is assumed to exist between the unit and the point if $R_p \leq R'$ or $\alpha_p \geq \alpha'$, where R_p is the range and α_p is the vertical angle from the center of the unit to the point. Thus, a point is in line of sight if it is within the unit's dominant mask (closer to the unit than the mask) or, regardless of range, above the unit's dominant mask.

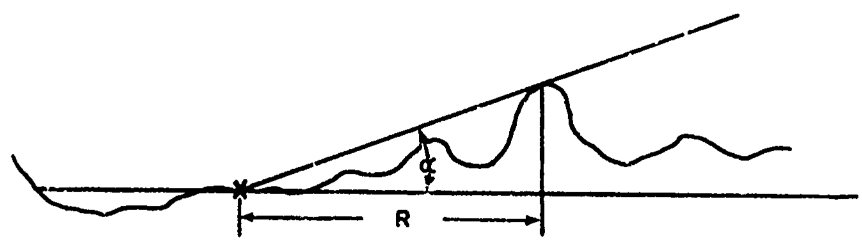
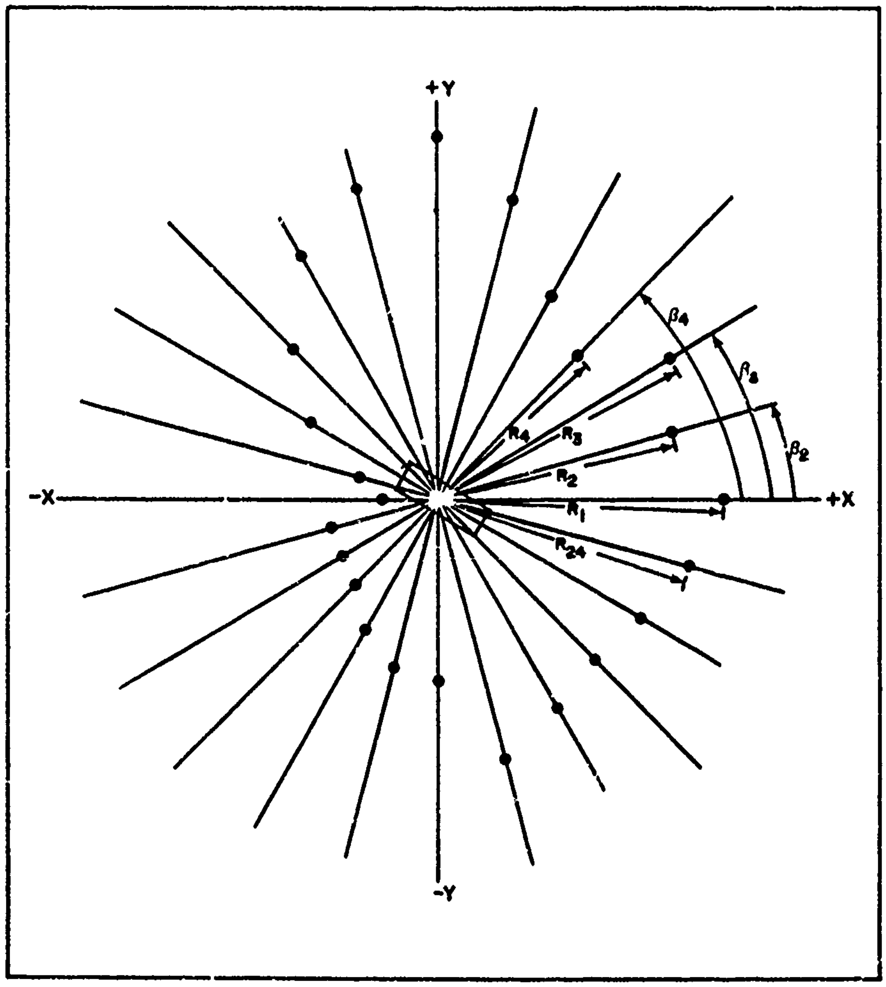


Figure 2-8. Dominant Mask Feature



● Denotes location of dominant mask feature on each radial line.

Figure 2-9. Dominant Masking Function

CHAPTER 3

INTELLIGENCE AND CONTROL MODEL

1. MILITARY ACTIVITIES REPRESENTED. The military activities simulated by the Intelligence and Control Model are summarized in Figure 3-1 within the area bounded by the dashed lines. These activities include:

- sensing and reporting of target elements
- time delays for collection, analysis, routing, and decision
- development of targets for fire missions
- intelligence analysis and maintenance of intelligence files
- decisions on information/intelligence flow and requests for fire support
- flow of information/intelligence between analysis points
- contents of periodic division intelligence summary.

These subjects are described in the following subparagraphs.

a. Sensing and Report. The term "sensing and reporting" is used here to denote the general area of detection and collection of information or intelligence on units of the opposing force and the summarizing of such information into sensing reports, which enter the intelligence chain. This area includes both information suitable for fire missions and information that may not meet the definition of an acquired target (Reference 1) but may contribute to the development of useful intelligence or acquired targets.

(1) Surveillance and Target Acquisition Functions. The surveillance and target acquisition functions (References 2, 3, 4) simulated by the Intelligence and Control Model are restricted to certain types of sensors or "collection systems" that may be organic to or attached to the respective opposing force and the firing artillery of the opposing force.

(2) Collection Systems. Individual sensor types or groups of sensor types constitute a collection system. Various such collection systems whose functions and output can be simulated by the Intelligence and Control Model are:

(a) Airborne observers in light observation helicopters (LOH) or fixed wing army light observation aircraft.

(b) Reconnaissance aircraft with MTI radar and real time data readout either onboard the aircraft or at a ground sensor terminal (GST) (typical of the Mohawk OV-1D aircraft).

(c) Air Force high performance reconnaissance aircraft equipped with visual observers and aerial camera systems.

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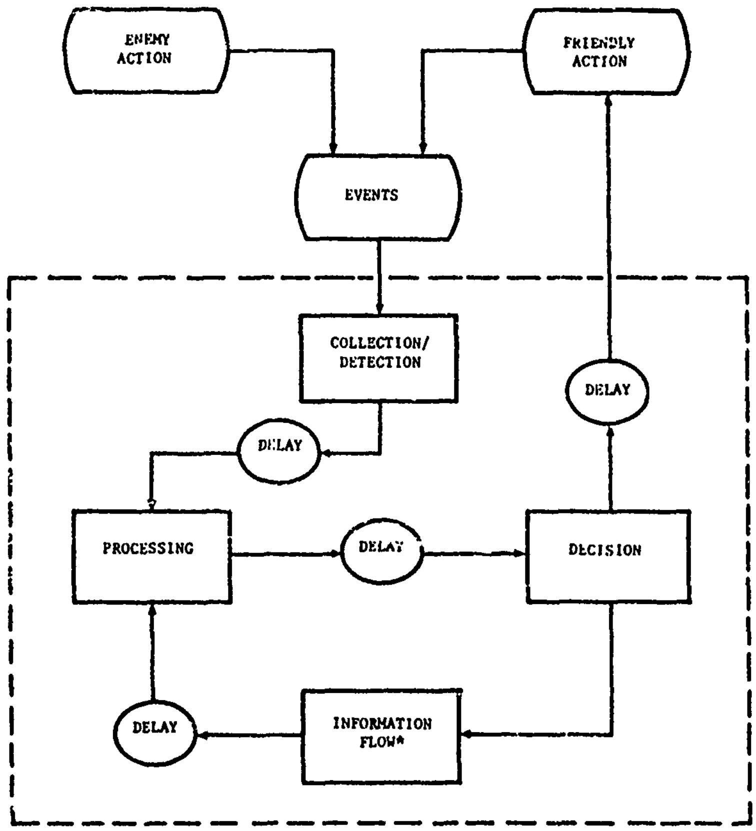


Figure 3-1. Intelligence and Control Activities Simulated

(d) Ground observation posts with moving target indicator (MTI) radars.

(e) Air defense radar sites.

(f) Unattended ground sensor (UGS) fields with associated monitoring posts.

(g) Countermortar and counterbattery radar sites.

(h) Ground combat forward observers with visual unaided and aided detection capabilities (internal to the Ground Combat Model).

(3) Target Detection Process. The process of detection, recognition, identification, and location of a target or other object by a component sensor of a collection system depends on many parameters; some dynamically changing and others relatively stationary during the time span of the interaction between the sensor and target. Some of the primary factors impacting on the target detection process are:

- relative location of target and sensor
- target characteristics (e.g., motion and camouflage)
- sensor characteristics (e.g., range, field of view, scan rates, and reliability)
- environmental features (e.g., maintenance of line of sight, terrain masking, cover, vegetation, weather, and light conditions)
- operator performance (e.g., orientation of sensor, scanning patterns, prior knowledge of potential target areas, and false target signatures identification.

In the Intelligence and Control Model, various degrees and combinations of these factors are simulated by the submodels representing the detection or collection function performed by collection systems. The specific factors considered are discussed in detail within the descriptions of each submodel, together with the logic used to simulate the recognition, identification, and reporting of discrete target elements within resolution units of the DIVWAG Model.

(4) Reporting of Detections. When information believed to be of interest is obtained by a sensor or collection system, this information is entered into the intelligence and/or fire support information channels in the form of a sensing report. The model simulates this activity by introducing delay times depending upon sensor type and target size to represent the time necessary to monitor the target; recognize its significance; estimate its size; and collect, prepare, and report the information in a standard format. The sensing report information produced by the submodels includes the following principal items:

(a) Number of personnel and equipment items recognized and identified. (Up to 15 categories or target types are available for use within some of the submodels)

(b) Time at which the sensing was made.

(c) Estimated location of the target unit.

(d) Activity of the target unit.

(e) Direction of movement and speed of unit if the target is moving.

(f) Identification of the collection system and/or sensor type responsible for the detection.

b. Time Delays for Collection, Analysis, Routing, and Decision. Time consumed during intelligence collection, intelligence analysis, routing, and the use of the information in decisions concerning fire support and information flow has a critical bearing on the usefulness of this information. The Intelligence and Control Model provides for the introduction of time delays covering each of these elements in the intelligence chain. Time delay for collection was described above. Delay for the processing and analysis of a sensing report and the drawing of inferences or conclusions depends in the model upon the echelon receiving the report, as does the time required to reach a decision on further routing of the newly processed intelligence and whether a request for fire support is justified. Time for the handling of message traffic is included in the other functional delays described above, without provision for queueing delays. All delay values used in the model are fixed values from input data tables.

c. Development of Targets for Fire Mission. Effective fire support by ground based artillery, attack helicopters, or CAS requires target acquisition and target intelligence functions (References 4, 9, 10) that can differ substantially from the intelligence functions that best yield other types of intelligence, such as order of battle, assessment of enemy capabilities, and evaluation of possible future courses of enemy action. While intelligence analysis of the latter type can often contribute very valuable targets, which would otherwise go unrecognized, a large part of fire support activity tends to depend on close linkage between sensors and fire support means, with a minimum of time delay between target detection and fire response. Effective use of non-nuclear munitions generally requires that targets be located within 200 meters (References 7, 11-13), and this in turn means that relatively small targets (say, through company size) will most often be identified for fire missions and that their location will be recent enough to minimize the likelihood of target departure. The Intelligence and Control Model provides separate channels for routing of target intelligence without the regular time delays and the process of analysis, updating, rerouting, and re-analysis of the information. The target intelligence channels send the original sensing

report directly to the Area Fire/TACFIRE and Air Ground Engagement Models after preliminary screening and analysis steps and decisions are performed. These steps establish type and size of target and filter out reports that are redundant with fire support requests filed earlier. Decisions involve whether the target qualifies for fire support, and if so, the type of fire support to be requested.

d. Intelligence Analysis and File Maintenance. A central element in the process known as intelligence analysis is the comparison of a new report or element of information with information already in the intelligence files. Following preliminary screening and classification of a new report, careful comparison with existing files permits inferences to be made concerning the possible uniqueness or redundancy of the new report. If a report is essentially unique, it becomes a nucleus in the file for subsequent comparisons of other new reports and will often be rerouted to other appropriate intelligence centers for further scrutiny. Also, any report may engender redirection of collection efforts or possibly be cause for tactical decisions. If a report is essentially redundant with existing file data, the new report serves to reconfirm the existence of the previously detected enemy unit and possibly to add details to the existing file, in which case the updated file or facts may often be routed to other analysis centers for information or further examination. In some cases the existence of entirely new units in the area of interest can be deduced from several individual reports compared in a proper framework. The ability to make such comparisons is limited by the information in the existing file and the ability to readily retrieve the pertinent information, as well as by the imagination of the analyst in choosing items to compare and in recognizing similarities and differences of significance. To facilitate retrieval, files must be of limited size; and they must be pruned of irrelevant and outdated information.

(1) While any of the items in a sensing report can occasionally be important to this comparison process, certain informational elements can be of frequent importance, such as sensing time; location; estimated size of unit; estimated type of unit; and estimated activity, including direction and speed, if moving. The identification of certain types of materiel can be an important clue to the type and identity of unit (Reference 3).

(2) The Intelligence and Control Model simulates the intelligence analysis and file maintenance functions just described, using the information in each new sensing report and comparing it with 24 information items maintained in each report record in an intelligence file unique to each intelligence analysis center. Intelligence centers are simulated at maneuver battalion, brigade or regiment, and division levels. A battalion intelligence file in the model can store up to 10 reports; a brigade/regiment file, 20 reports; and a division, 100 reports.

e. Decisions on Information/Intelligence Flow and Requests for Fire Support:

(1) The routing of information or intelligence among intelligence analysis centers and command elements at the several echelons, both vertically between echelons and laterally between units at a given echelon, can vary considerably in reality. Policies and practices reflect the tactical situation and the preferences of cognizant personnel (Reference 4). In a given situation, with the same personnel, however, basic routing rules tend to be applied (Reference 4). Criteria for rerouting a report to friendly units at the same or superior or subordinate echelons tend to involve the type and size (threat) of the enemy unit reported, the location of the enemy unit, and the areas of interest of the various friendly units or elements. Not infrequently, it may be standing policy that, on receipt, new sensing reports are simultaneously routed to several echelons and intelligence analysis centers (Reference 4). The Intelligence and Control Model simulates the sequential routing structure, in which each report is considered against a set of input tables (one each for Red and Blue) of routing criteria before it is transmitted to any further intelligence analysis center.

(2) Requesting of fire support to be provided by ground-based artillery, attack helicopters, and TACAIR will depend in reality on the needs of the tactical situation and the availability of fire support resources. The nature and location of the potential target are important considerations in this process. Generally, certain basic rules will tend to be applied. The Intelligence and Control Model uses such a set of rules in the form of a decision criteria matrix. This matrix (one each for Blue and Red) involves type and size of target and preferred and alternate fire support means to be employed for several different tactical conditions. When the Intelligence and Control Model issues a request for TACAIR or attack helicopters, and if resources are unavailable or if visibility is inadequate, the request returns and is rerouted to an alternate means.

f. Flow of Information/Intelligence Between Analysis Centers. The results of analysis at any intelligence center are generally communicated to associated centers at higher and lower echelons, either on a piecemeal basis or a periodic summary report basis, or by both methods. New inferences or facts are thus made a part of the background material that the receiving center uses in its analysis so that the product of the whole intelligence chain is greater than would be the product of individual isolated analysis centers. The Intelligence and Control Model simulates this flow on a piecemeal basis only. In the model, new or modified sensing reports are routed to all other centers that qualify for receipt according to an input criteria table, provided that the identical version of the report has not already been sent to the otherwise qualifying center. A substantial flow of modified or updated information (sensing reports) thus occurs among the intelligence analysis centers in the model.

g. Contents of Periodic Division Intelligence Summary. Periodic summaries of current status and recent developments in the intelligence picture are generally prepared by the intelligence analysis staffs at various echelons (Reference 4). The Intelligence and Control Model provides such a report, printed

at the end of each period of play, to assist gamers in period turnaround. This report is, in effect, a cumulative status report for the division as a whole, reflecting the end-of-period contents of the intelligence file of the division intelligence analysis center. For each sensing record that reached the division file, was not deemed redundant with a record already in the file, and was not discarded from the file in favor of a more recent or more pertinent record, this report lists the following:

(1) Estimated x-y coordinates of the enemy unit.

(2) Estimated size (echelon) of the enemy unit.

(3) Estimated activity of the enemy unit.

(4) Estimated type of the enemy unit.

(5) Direction of movement if the unit was detected moving.

2. DESIGN OF THE INTELLIGENCE AND CONTROL MODEL:

a. Constituent Submodels. The Intelligence and Control Model consists of four basic submodels: Collection System Control, Collection, Creative Processing, and Decision. Each of these submodels covers a broad functional area and either contains, is a part of, or supports several programs or subroutines. This paragraph contains a brief description of the four submodels and their interrelation. Details are given in subsequent paragraphs.

(1) Collection System Control Submodel. This submodel is comprised of the logic within the various collection and decision routines which either transforms DSL input orders into control parameters for the various collection systems or automatically initiates control of sensor movement during the course of the dynamic game period. For ground-based sensors, this activity is represented in the movement of collection system sites in response to changes in the deployment of forces and is performed in the Subroutine MOVSEN. For airborne collection systems, logic to respond to DSL orders, initialize air reconnaissance mission units, generate flight legs, activate onboard sensors, and complete flight missions is contained in the air reconnaissance routines RECONDT, MOVREC, RECHOM, and RECEND and to some extent in the detection routines RECON1, RECON2, and RECON3.

(2) Collection Submodel. The primary task of the Collection Submodel is to simulate the sensing and reporting functions of the individual collection systems considered. In general, each collection system is represented by a separate program or subroutine that contains the detection, identification, report preparation, and report transmission logic characteristic of the sensor(s) and personnel involved in the process at this site or platform. The description of the Collection Submodel (Paragraph 4, below) separates the discussion of the representation of a force's reconnaissance/surveillance and target acquisition capability into airborne collection systems and ground-

based collection systems. The air reconnaissance and surveillance routines are controlled within one logic framework of the Intelligence and Control Model, and the ground-based sensor systems are treated in another section.

(a) Airborne Collection Systems. Airborne collection system logic is developed around an event sequencing structure in which each collection system has the status of a DIVWAG resolution unit. The detection trials constitute successive collection events for the unit, and thus the model logic is entered at each subsequent trial as predicted by logic within the Collection Submodel itself. Thus, the representation is self-triggering and allows the dynamic development of detection trials in response to the motion of the aircraft mission unit involved. This approach also facilitates use of internal control logic to alter mission unit objectives.

(b) Ground-Based Collection Systems. The event sequencing logic used for the ground-based sensor is different from that used for the airborne collection systems. Primarily, this is due to ground-based sensor sites not having unit status within the game. Since the ground-based collection systems (excluding the ground combat forward observers) currently have a detection capability against moving units only, the event sequencing is passive or externally triggered, and the detection trial logic is entered only when a potential target unit initiates a model move segment. Likewise, the detection trial for acquisition of firing artillery is triggered by the fire event that occurs for each volley of every fire mission.

(c) Target Acquisition and Fire Support Response. The sensing reports generated within each collection submodel form the basis from which all intelligence information is produced within the Intelligence and Control Model. Likewise, every DIVWAG model-generated TACAIR mission, DAFS mission, and artillery fire mission is based on a sensing report or combination of sensing reports originating in one or more of the component collection submodels.

(3) Creative Processing Submodel. This submodel simulates the intelligence analysis process, including preliminary screening and classification, comparison with the contents of the intelligence file, and file maintenance, on receipt of a sensing report by battalion, brigade/regiment, or division. The output of the Creative Processing Submodel is routed to the Decision Submodel, with time delays.

(4) Decision Submodel. This submodel determines the dissemination of intelligence from one echelon or unit to another and decides when and what type of fire support to request for target intelligence.

b. Macroflow of Intelligence and Control Model. The macroflow of the Intelligence and Control Model, with emphasis on the interaction of the constituent submodels, is shown in Figure 3-2. Principal subroutines involved are also identified in this figure.

INTELLIGENCE AND CONTROL MODEL MACROFLOW

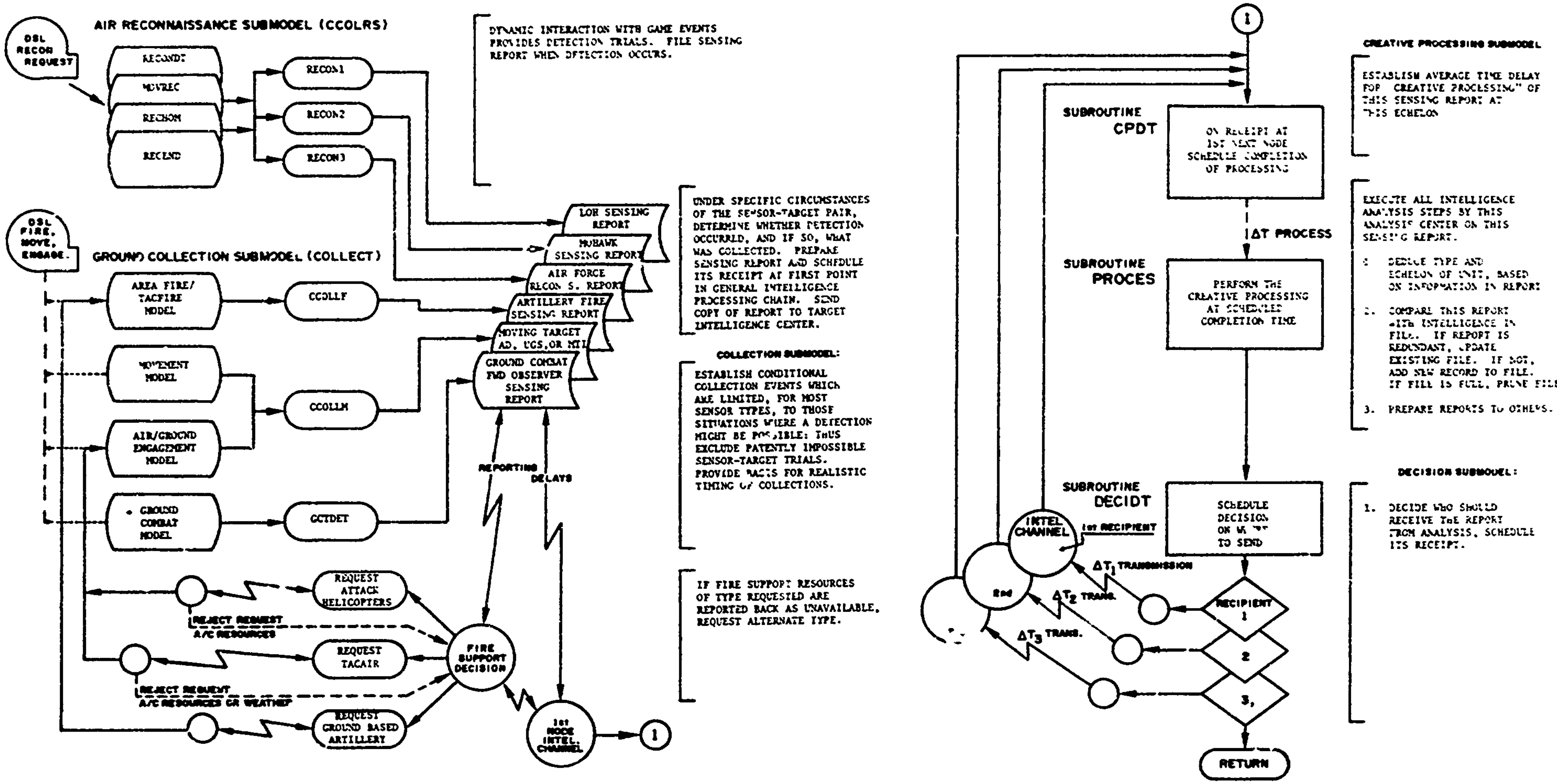


Figure 3-2. Intelligence and Control Model Macroflow

3. INTELLIGENCE AND CONTROL MODEL INTERACTION WITH OTHER DIVWAG MODELS:

a. General Dependencies. The Intelligence and Control Model interacts directly or indirectly with most of the combat activity submodels of the DIVWAG system. Of primary importance are the interactions with the Environment, Ground Combat, Area Fire/TACFIRE, Air Ground Engagement, and Movement Models. Output of the Intelligence and Control Model provides fire missions for Area Fire/TACFIRE and Air Ground Engagement Models, while inputs to the Intelligence and Control Model are provided by all of the above models. The nature of the various dependencies is described below.

b. Environmental and Movement Interactions. These models provide many of the parameters used by the collection submodels to simulate detection activities. As such they represent primary control parameters of the Intelligence and Control Model and determine to a large extent the performance limitations of the individual collection systems.

(1) Movement Interactions. The movement scheduling portion of the Movement Model provides the trigger for detection of air and ground moving targets by air defense radar sites and MTI ground radar sites or UGS field monitoring posts, respectively. Whenever a moving ground (air) unit begins a DSL move segment (flight interval), and also when a ground unit crosses a terrain cell boundary (model move segment start point), the Intelligence and Control Model's conditional collection of moving targets (CCOLLM) routine identifies the potential ground-based collection systems for which the moving unit may become a potential target.

(2) Environmental Interactions. The environmental model provides each collection submodel with environmental conditions required to simulate the performance of the respective collection systems. For airborne visual observers, airborne radars, and aerial camera systems, this includes visible ranges or light levels, terrain background visual reflectances, terrain radar reflectances, precipitation levels, and line of sight terrain parameters for the terrain and forest type in which the target is located. For ground units and nonvisual sensors in air reconnaissance aircraft, the line of sight model provides the range to mask and mask angles of the target units involved.

c. Firepower Model Interactions. A significant portion of the Intelligence and Control Model's interaction with the DIVWAG system exists in form of direct interactions with the Ground Combat Model, the Area Fire/TACFIRE Model, and the Air Ground Engagement Model. It is through these interfaces that the DIVWAG automatic firepower events are scheduled, executed, and responded to during the dynamic period of the game. These interfaces are described for each of the firepower models in the following subparagraphs.

(1) Ground Combat Model Interactions. The acquisition of targets and intelligence information by forward observers of maneuver units engaged in ground combat is simulated within the Ground Combat Model. The sensing reports produced are sent to the Intelligence and Control Model for fire support consideration and intelligence analysis.

(2) Area Fire/TACFIRE Model Interactions. The TACFIRE portion of the Area Fire/TACFIRE Model responds to fire mission requests generated by the Intelligence and Control Model. The fire missions requested are produced by the Intelligence and Control collection system submodels and considered for artillery fire support in the DECIDE portion of the Intelligence and Control Model. The assessment portion of the Area Fire/TACFIRE Model serves as a trigger to initiate a screening of opposing countermortar/counterbattery radar sites to determine if the volley being assessed was tracked and the fire unit located. If the fire unit is located, the collection system submodel (CCOLLF) enters a sensing report of the fire unit into the Intelligence and Control Model.

(3) Air Ground Engagement Model Interactions. Target acquisitions in the Intelligence and Control Model collection submodels may also be considered for fire support by attack helicopters or TACAIR. If the target qualifies, and the request is accepted by the Air Ground Engagement Model, the mission is automatically executed. An interaction also exists between the enemy air defense and reconnaissance missions flown by the Intelligence and Control Model, wherein each air reconnaissance mission unit is vulnerable to enemy air defenses. The air attrition is discussed briefly in the Collection Submodel paragraph [4c(4)] and in detail in the Air Ground Engagement Model (Chapter 5).

4. COLLECTION SUBMODEL:

a. General:

(1) Scope. The Collection Submodel of the Intelligence and Control Model simulates the sensing and collection functions of various airborne and ground-based sensor collection systems. The collection systems simulated in detail within the submodel are Light Observation Helicopter (LOH) or fixed wing aircraft with visual observers, Mohawk OV-1D with moving target indicator (MTI) radar and ground sensor terminal (GST) for real time data readout, Air Force high performance reconnaissance aircraft with visual observers and aerial cameras, observation posts with MTI radars, air defense radar sites, unattended ground sensor (UGS) fields, and countermortar/counterbattery radar sites. In addition to these collection systems, the collection of information attributable to maneuver units engaged in ground combat is simulated by the Ground Combat Model. These collection systems with their associated component sensors generate the input information used within the Intelligence and Control Model and thus represent the basis from which all intelligence information within the model is ultimately derived. To allow the individual collection systems to generate discrete sensing reports, a stochastic approach is used in most of the collection system submodels. The number of targets reported is based on expected value calculations as are all of the environmental parameters. This combination of stochastic techniques for event sequencing purposes and the expected value calculations for operations of high volume permits economy of computer usage as well as reasonable assurance that the game results will not be driven by random chance.

(2) Description of the Submodel. The Collection Submodel is described in three sections. The first section treats the submodel's representation of target units, line of sight, sensing report information, and other details pertinent to all the collection systems in general. The second section describes airborne collection systems, and the third section describes ground-based collection systems. Figure 3-3 illustrates a macroflow of the Collection Submodel routines.

b. Specific Collection Submodel Design Considerations:

(1) Collection Systems. The term collection system in the model is used to describe the aggregate of sensor(s), operator(s), and auxiliary equipment whose combined activity may result in the detection, recognition, identification, and subsequent reporting of a target to appropriate fire support and/or intelligence channels. Each of the collection systems represents a means of acquiring intelligence or target information through the employment of component sensors from either a ground-based location or a moving airborne platform. Each is described by a submodel that controls the collection process of the component sensors within this particular system and produces sensing reports from detections of enemy targets and activity and the subsequent recognition and identification of the targets by the operator or operators. Each collection system contains at least one sensor type and in some instances more (e.g., the LOH may have both unaided visual and binocular aided observers on board). The various component sensors currently considered by the model are listed below:

- MTI, long range
- MTI, medium range
- MTI, short range
- UGS (individual types)
- Air defense radar
- Countermortar/counterbattery dual beam type radar
- Countermortar/counterbattery continuous tracking type radar
- Airborne SLAR MTI radar with GST
- Airborne unaided visual observer
- Airborne binocular aided observer
- Aerial camera, panoramic
- Aerial camera, vertical
- Aerial camera (right, left, and front oblique)
- Forward observer (within Ground Combat Model).

(2) Target Unit Representation:

(a) Target Subunits. To facilitate modeling the detection capabilities of various collection systems in reasonable detail against large battalion-sized units composed of bands containing many discrete target element types, the unit is subdivided into subunits for purposes of performing the collection trial. The number of subunits is dependent upon the unit's width, depth, number of bands, and the sensing characteristics of the sensor type involved. Figure 3-4 illustrates a battalion-sized maneuver unit

COLLECTION SYSTEM SUBMODEL MACROFLOW

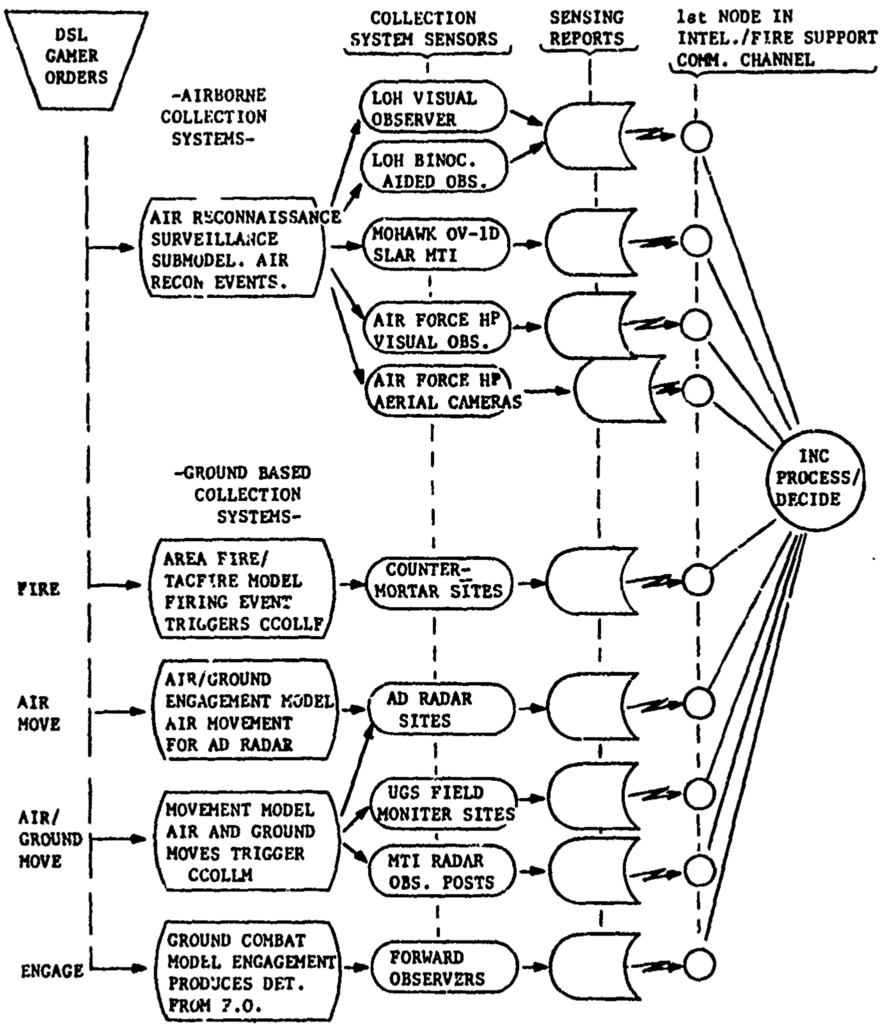


Figure 3-3. Collection Submodel Macroflow

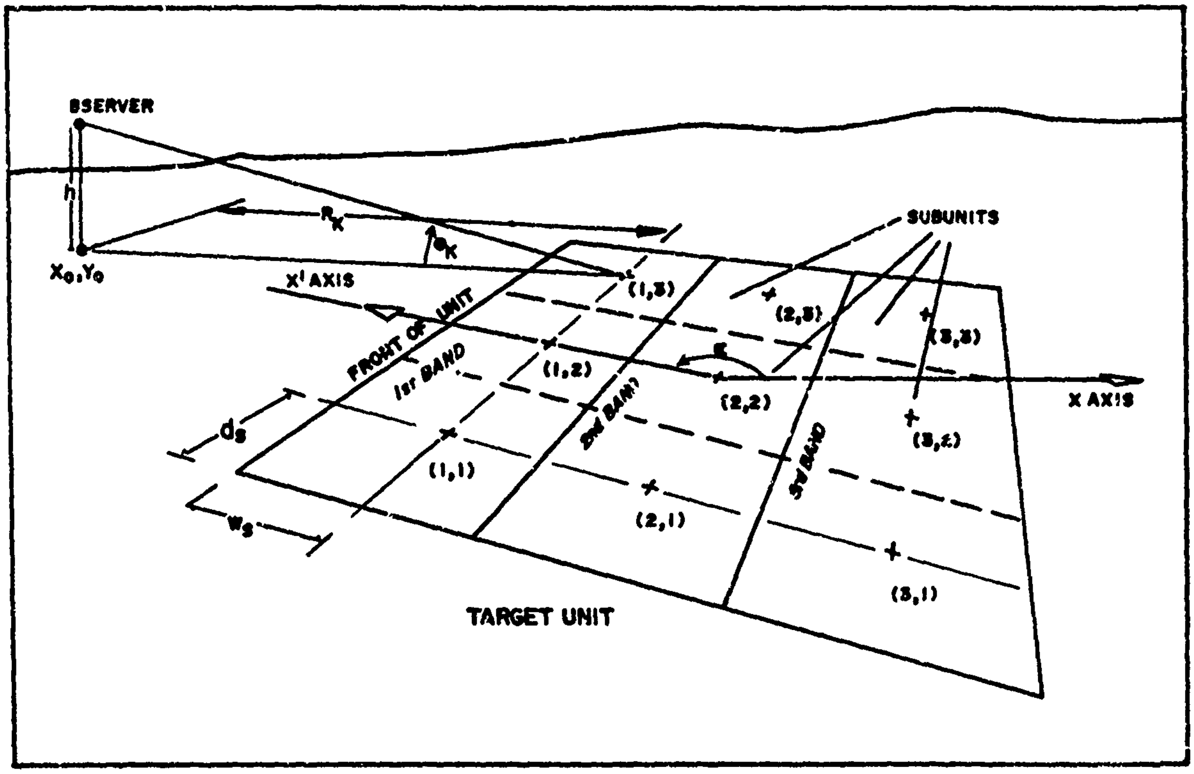


Figure 3-4. Target Subunits.

subdivided into subunits. The subunits form the aggregate against which the collection system's detection capabilities will be examined. Thus, for example, a visual observer may have line of sight on only a single subunit of the target unit and be masked from viewing the rest of the unit. Target subunits are thus artificial divisions of units into smaller groups of targets against which the performance of sensors can be more adequately simulated.

(b) Target Element Types. To represent the interaction between component sensors and targets, the following target elements have been selected as representative of the target unit or subunit:

- Personnel
- Wheeled vehicles
- Tanks
- APCs and APC-like vehicles
- Artillery tubes
- Artillery missiles
- Air defense guns
- Air defense missiles
- Aircraft.

Only personnel who are dismounted and therefore susceptible to detection as individuals are considered as personnel target element types.

(3) Line of Sight Representations. Two distinct line of sight representations are used within the Intelligence and Control Collection Submodel. One of these involves the use of a dominant mask function as described in Chapter 2, and the other involves an RBAR parameterization scheme similar to the RBAR equation used in the Ground Combat Model.

(a) Dominant Mask Function (DMF). The LOS considerations for the ground-based MTI radars, air defense radars, Mohawk OV-1D SLAR MTI, and aerial camera sensors are representated by the DMF LOS calculation. This representation is basically a long range LOS calculation and thus is used in characteristic sensor-target interactions where large range separations exist (i.e., greater than 2 to 3 kilometers). The decision as to line of sight is a simple yes or no as returned from the LOS function routine for the particular combination in question. It is a point to point LOS function derived from a 500-meter elevation grid.

(b) RBAR Parameterization. Following the approach taken in the Ground Combat Model in usage of the RBAR LOS representation, the air reconnaissance submodels of the Intelligence and Control Model use an altitude parameterization of the RBAR equation to establish probability of line of sight for an airborne visual observer. The equation has the following form:

$$P_{LOS}^{ij} = \left(1 + \frac{2r_{ot}}{\bar{r}_{ij}}\right) e^{-\frac{2r_{ot}}{\bar{r}_{ij}}} \qquad (3\text{-}1)$$

where r_{ot} is the ground separation between the observer (o) and the target (t), and $\bar{r}_{ij}$ is given by:

$$\bar{r}_{ij} = \bar{r}_o^{ij} \ (1 + 0.006h) \qquad (3\text{-}2)$$

where h is the altitude of the observer above the target, and $\bar{r}_o^{ij}$ is the RBAR parameter for forest conditions index i and terrain conditions index j. Two forest types and three terrain types as illustrated in Figure 3-5 are considered within the model. Equation 3-1 is an approximate parameterization of data used in Reference 25 and represents the general trends of line of sight probabilities versus altitude discussed in Reference 30. The equation represents a variation in the LOS function as the observer is elevated above the target. Figure 3-6 illustrates the line of sight curves resulting from Equation 3-1.

Forest Index	Roughness and Vegetation Index	RBAR (Meters)
0	1-3	2600
0	4-6	1600
0	7-9	900
1	1-3	2100
1	4-6	[illegible]200
1	7-9	600

Figure 3-5. Intelligence and Control Model Line of Sight RBAR Parameters

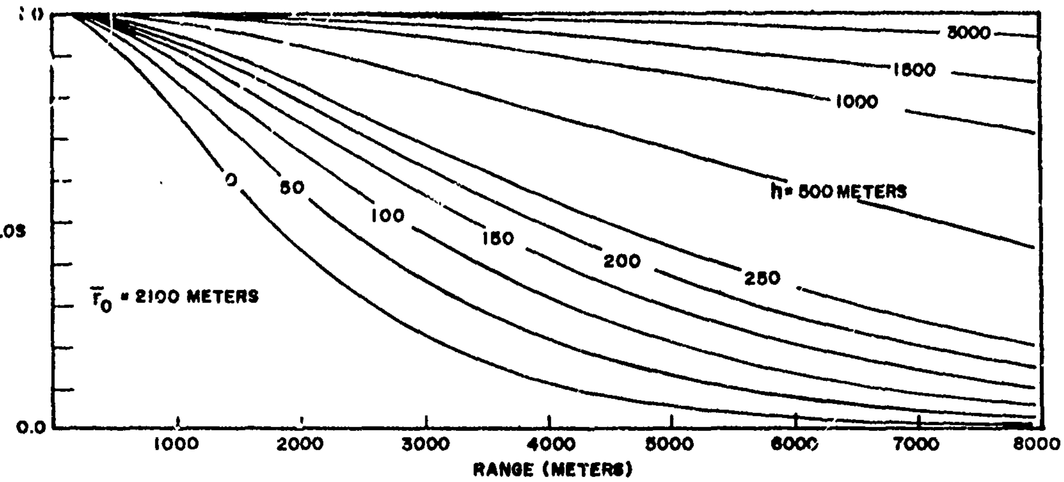


Figure 3-6. Typical Intelligence and Control Model Line of Sight Curves

c. Air Reconnaissance and Surveillance Collection Submodel (CCOLRS):

(1) General Submodel Descriptions. A significant amount of intelligence information is expected to result from a force's air reconnaissance and surveillance capability; therefore, considerable effort is devoted to the development of a representative set of routines to simulate the performance of these collection systems.

(a) Air Reconnaissance Macroflow. Figure 3-7 illustrates the routines in the submodels that initiate and perform air reconnaissance missions. The logic in these routines is discussed in detail in the following subparagraphs in terms of the initiation of the reconnaissance mission, the collection or sensing logic used for sensors onboard each collection system, the reporting of sightings, and the interpretation of processed film obtained during the mission.

(b) Air Reconnaissance Mission Types. Three distinct types of air reconnaissance aircraft are represented. These are (1) light observation helicopter (LOH) mission or fixed wing Army aviation, RECON1; (2) Army Mohawk OV-1D reconnaissance aircraft, RECON2; and (3) Air Force high performance aircraft, RECON3. Each of these routines contains the collection logic of the respective collection system.

(2) Gamer Initiation of Reconnaissance Missions. The DSL RECONNOITER and FLY orders provide the necessary control information to initiate the reconnaissance mission, identify the sensor types carried onboard, develop the

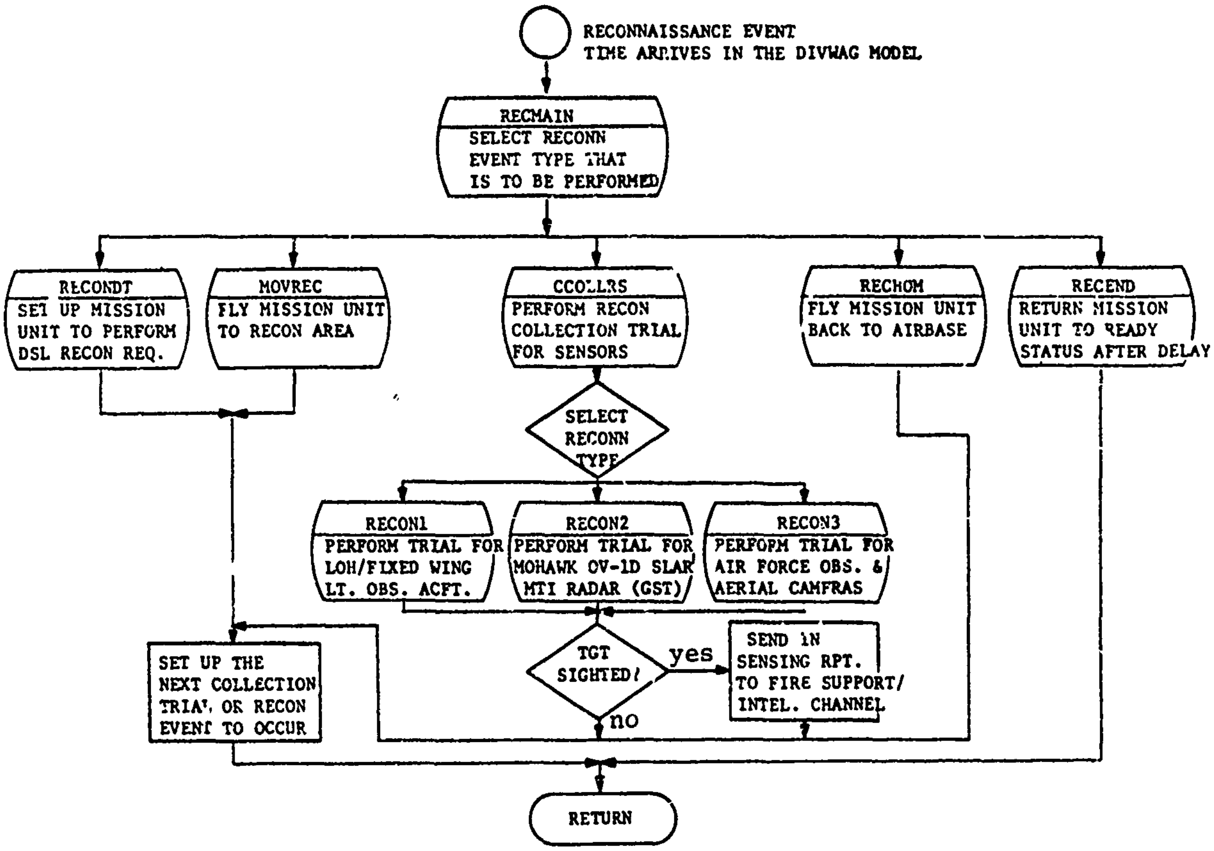


Figure 3-7. Air Reconnaissance/Surveillance Submodel Macroflow

flight path for the mission, and control sensing equipment onboard the aircraft. The DSL orders for the three reconnaissance mission types considered in the submodels contain the following data:

- 4-character reconnaissance mission control code
- flight interval endpoint coordinates for route reconnaissance or boundaries of area reconnaissance missions
- altitude at which mission is to be flown
- flight speed of aircraft.

(a) Reconnaissance Mission Unit. In order to initiate an LOH type reconnaissance mission the gamer must give the airbase or unit (described in the DIVWAG system with a specific unit type identifier) a DSL order requesting the mission. The request is made to the airbase or to the unit from which the mission is to be flown and will result in a mission unit of a single aircraft being extracted from the unit or airbase and assigned the reconnaissance mission.

(b) Reconnaissance Mission for Nonmission Unit. The request for a Mohawk or Air Force reconnaissance mission is made directly to the unit the gamer wishes to send. Thus, single reconnaissance aircraft must be given unit status in the initialization of the game. Since a relatively small number of Mohawk or Air Force reconnaissance sorties are expected to be available to a division, this restriction to individual unit identity should not be cumbersome.

(3) Flight Initiation Routines. The routines used in the model to perform the reconnaissance flight initialization and return to base bookkeeping functions are RECONDT, MOVREC, RECHOM, and RECEND.

(a) RECONDT. This routine establishes the mission unit if necessary and determines the time required to fly the unit to the sensor activation point in the mission.

(b) MOVREC. The unit is moved to the sensor activation point by this routine, the location updated, and fuel consumption accounted for.

(c) RECHOM. Once the reconnaissance mission is completed, this routine sets up and determines the time to fly the mission unit from the reconnaissance endpoint back to its home airbase.

(d) RECEND. This routine returns the status of the mission unit to ready for another reconnaissance mission after appropriate delays (e.g., to refuel and change film).

(4) Air Attrition Effects. The attrition of air reconnaissance aircraft is simulated by the routines of the Air Attrition Submodel. After the simulated detection logic has been completed in the collection routines of CCOLRS for each projected flight leg, the Air Attrition Submodel simulates the actual exposure to enemy air defense weapons and the actual movement of

the mission along the flight leg. If an engagement by air defense sites occurred during the flight leg the expected probability of loss of the mission unit is returned to the reconnaissance routines for consideration before subsequent flight segments are initiated. To establish aircraft losses, a random number between zero and one is compared to the expected probability of aircraft loss. If this random number is less than the loss probability the aircraft is considered to have been lost on the previous flight leg. If the unit has onboard camera systems with exposed film, the potential sensing reports previously stored for this mission are eliminated from the delayed report file and thus are lost to the intelligence files.

(5) LOH/Fixed Wing Army Aviation Observation Aircraft (RECON1). The submodel RECON1 simulates the performance of visual observers onboard light observation aircraft. The DSL mission order, flight patterns, sensing logic, and reporting procedure are discussed in the following subparagraphs.

(a) DSL Control Code for RECON1. The first character of the control code is an H or F and represents the type of observation aircraft, helicopter or fixed wing. The second character specifies the mission type as R if it is to be a route reconnaissance. If an area reconnaissance is desired, the second character is an integer specifying the length of the mission in 15-minute increments. The third character specifies the route deviation limit in kilometers (corridor width) which the aircraft will not exceed during the flight. For example, in the control code of HR26, the integer 2 in the third position specifies that the LOH will reconnoiter along the DSL route with a corridor width of 2 kilometers and consequently will never exceed the 1-kilometer route deviation limit to either side of the center route line segment. For an area reconnaissance mission, the third character is used in the same manner and effectively creates a density of reconnaissance coverage (i.e., successive passes over the assigned area will be separated by approximately the corridor width). The fourth character specifies the sensor combination load onboard the observation aircraft.

(b) Mission Unit Flight Intervals. The model allows for two distinct reconnaissance and surveillance mission types to be flown. These are the route reconnaissance and the area reconnaissance missions, illustrated in Figure 3-8. As discussed above, the route interval endpoints specified in the DSL order form the center of the actual route flown by the aircraft. In the case of the area reconnaissance request, the coordinates specified are the four corners of the area over which the reconnaissance mission is to be flown. The order of the points appearing in the DSL order is such that P_1, P_2, P_3, and P_4 (shown in Figure 3-8, part B, Area Reconnaissance) are in counterclockwise order around the enclosed area. Also $\overline{P_1P_2}$ is always the rear boundary from which the coverage of the area will be initiated by the model. Using this area, the rear and forward boundaries, and the corridor width, a set of flight intervals is automatically computed by the model to allow complete coverage of the assigned reconnaissance area.

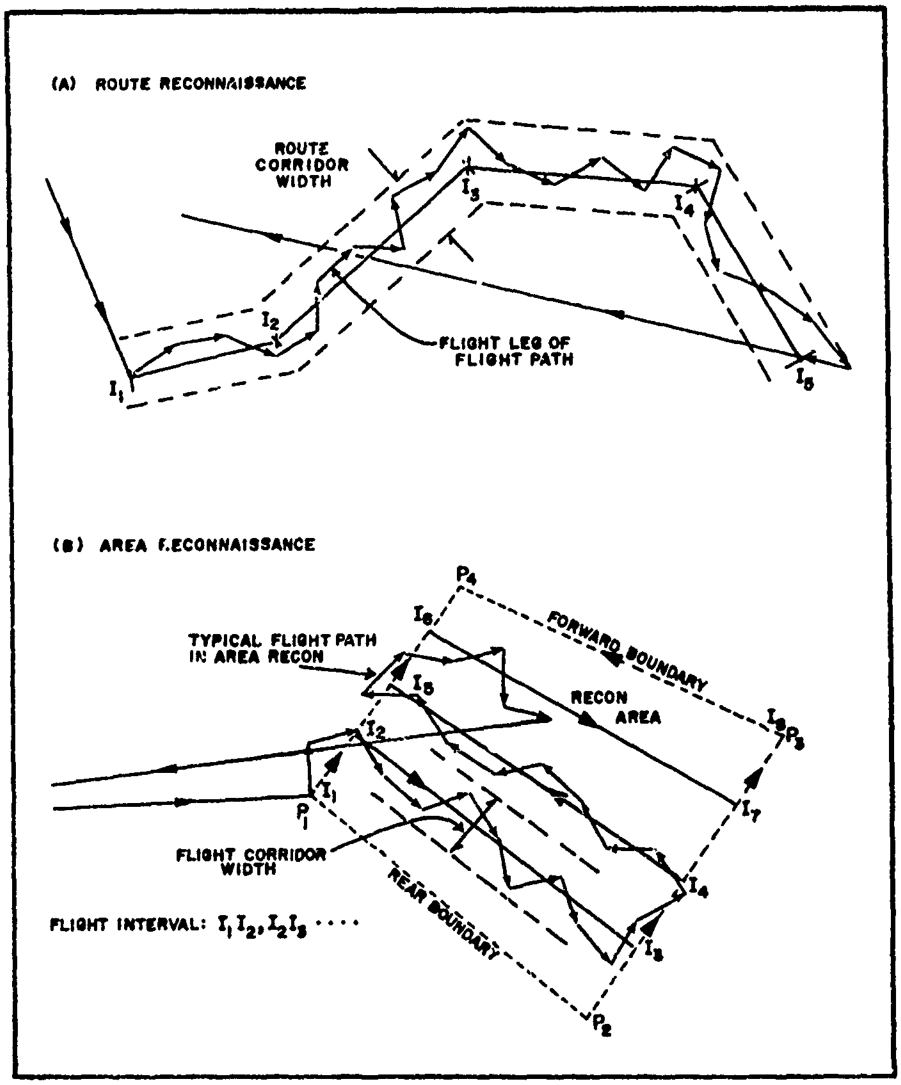


Figure 3-8. RECON1 Route and Area Reconnaissance.

(c) Mission Unit Flight Legs. The actual flight path flown by the mission unit is also illustrated in Figure 3-8. The flight leg length is currently fixed at 1500 meters. The leg is long enough to permit relatively efficient computer running time, yet short enough to allow adequate calculations of such parameters as range to be made from the midpoint of the flight leg. The successive flight legs along a route interval are established by randomly choosing an angle between $-\pi/2$ and $+\pi/2$ radians centered in the direction of the current route interval and then computing the endpoint of a projected 1500-meter flight leg in this direction. If the endpoint falls outside the route corridor, another random angle is chosen and the calculation repeated. This process is iterated until a flight leg which lies inside the corridor is obtained.

(d) Collection Trial Geometry. Figure 3-9 illustrates the geometry of the search sectors used to produce collection trials for an LOH or fixed wing observation aircraft. Successive look sectors are overlapped with the rear sector boundary perpendicular to the flight leg and at the start point of the actual flight segment on which the collection trial is to be performed. An expanded look sector is also shown in Figure 3-9.

(e) Event Sequencing of Collection Trials. The basic unit of time simulated in RECON1 is the length of time required for the mission unit to complete the 2200-meter flight leg. During this t period the geometry of a search sector is used to establish the location of the potential target subunits, compute line of sight probabilities, determine terrain cell locations of subunits, and compute values for all range-dependent quantities. The point from which all range calculations are made is the midpoint of the flight leg. This is equivalent to using the averages of the ranges from the startpoint of the flight leg and the endpoint of the flight leg. The routine, RECON1, is entered at current game time with the mission unit located at the startpoint of the flight leg. At this time the model predicts if a detection will be made along the upcoming flight leg. If a detection will occur a sensing report is created. This report's entry into the Intelligence and Control Model's fire support and intelligence channels will be delayed until the actual time at which the sighting and reporting is determined to have occurred.

(f) Identification of Potential Target Subunits. Following the procedure of subdividing battalion-sized units into subunits, the initial process in the collection trial consists of forming a matrix containing all target subunits that are within the boundaries of the search sector.

1. Search Sector Radius. The ground radius of the search sector, R_S, is set as follows:

$$R_S = \text{MAXIMUM}\left[5000 \text{ meters}, (V_R{}^2 - h^2)^{1/2}\right] \qquad (3\text{-}3)$$

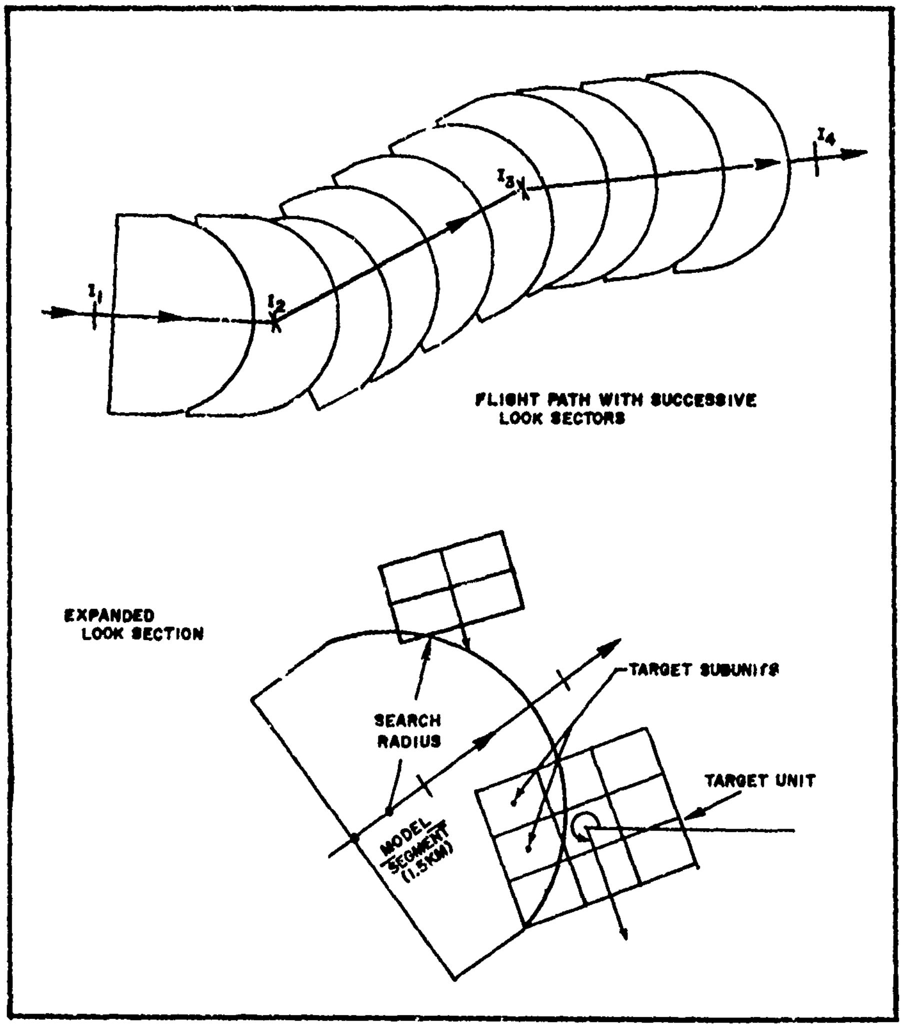


Figure 3-9. Search Sector Geometry for RECON1.

where V_R is the visible range (meters) and h is the altitude (meters) above ground. Using this search radius centered at the midpoint of the flight leg, all units whose centers lie within this circle are located and identified by the search routine. The resulting list identifies the units which may be vulnerable to detection by the mission unit in this collection trial.

2. Subunit Screening. Once a list of units is obtained, each unit is subdivided into its component subunits and screened for location within the search sector and line of sight as follows:

a. Number of Subunits. Each unit is divided into subunits according to the following rules. Rule 1: The number of subunits is equal to the number of bands, N_B, times the number of subunits per band, N_W, where N_W is given by:

$$N_W = \text{MINIMUM}\left[3, \frac{W_N}{1500}, N_B\right] \tag{3-4}$$

where W_N is the width of the unit in meters. Rule 2: If the unit is moving on a road, N_W is set equal to 1.

b. Subunit Locations. Subunit locations expressed in game coordinates are:

$$x_{I_B I_W} = x'\cos\alpha - y'\sin\alpha + x_u \tag{3-5}$$

and

$$y_{I_B I_W} = y'\cos\alpha + x'\sin\alpha + y_u \tag{3-6}$$

where x' and y' are given by:

$$x' = -d_S(2I_B - 1) + \frac{D_u}{2} \tag{3-7}$$

and

$$y' = -w_S(2I_W - 1) + \frac{D_u}{2} \tag{3-8}$$

The parameters, d_S and w_S, are the dimensions shown in the figure. I_B and I_W are the subunit's band and lateral indices, and D_u is the depth of the unit. The angle α is the orientation of the unit and the coordinates, and x_u, y_u are

the location of the center of the unit. The location of a subunit must be within the search sector for further screening to continue. These locations are computed in the subroutine XYSUB.

c. Subunit Target Elements. The target elements in each subunit are established as the number of elements within the subunit's band divided by the number of subunits per band. Subroutine NUMTGTS returns the number of target elements in a particular subunit.

d. LOS Screening. Once the number of targets, m_i, of each target type i has been established the probability of line of sight on at least one target is computed as:

$$P_{LOS}^{T} = 1 - \prod_{i}(1 - P_{LOS})^{m_i} \tag{3-9}$$

where P_{LOS} is given by Equation 3-1 where the terrain and forestation indices correspond to the values for the terrain cell in which the subunit is currently located. A decision as to LOS is made by comparing P_{LOS}^{T} with a random number between zero and one. If the subunit passes this LOS screen it is subjected to a fine LOS screen such that if the expected number of targets of type i in LOS, $\langle m_i \rangle$, is not greater than one for at least one target type, where $\langle m_i' \rangle$ is given by:

$$\langle m_i' \rangle = m_i P_{LOS} \tag{3-10}$$

then the subunit is dropped from further consideration. Each subunit which meets both of the LOS criteria is retained in the potential target matrix and will be considered in the detection trial.

(g) Subunit Detection Trial. After the potential target matrix has been created for this collection trial, the subunit targets are screened for possible detection. The initial step is to compute the single target detection probabilities for each target type; e.g., tank, personnel, APC, artillery gun. These probabilities are computed on the basis of a single glimpse lasting a time, t_g, and include effects of apparent target contrast, number of resolvable target subelements, and effective glimpse rate. These effects enter into the detection calculation as described in the following subparagraphs.

1. Single Target Element Detection Probability. The single target element detection probability per single glimpse given that the observer is looking at the target elements is expressed as:

$$PD^i = \int_0^{u=\langle n_t^i \rangle} \exp^{-\frac{1}{2}\left[\frac{1}{\sigma_R} \ln\left(\frac{u}{n_o^R}\right)\right]^2} d\left[\frac{1}{\sigma_R} \ln\left(\frac{u}{n_o^R}\right)\right] \tag{3-11}$$

or:

$$PD^i = \int_0^{\langle n_t^i \rangle} \frac{1}{u} \frac{1}{\sigma_R} \exp^{-\frac{1}{2}\left[\frac{1}{\sigma_R} \ln\left(\frac{u}{n_o^R}\right)\right]^2} du \tag{3-12}$$

where $\langle n_t^i \rangle$ is defined as the effective number of resolved target subelements, n_t^i is the number of resolvable target subelements under optimum contrast conditions, n_o^R is the number of resolvable target elements required for a 50 percent recognition level, and σ_R is the variance of the recognition level about the 50 percent level. Currently, the values being used for n_o^R and σ_R are parameters which fit the detection curves presented in Reference 25.

a. Number of Resolvable Target Subelements. The number of resolvable target elements is computed as the ratio of the solid angle subtended by the target, $d\Omega_i$, to the minimum resolvable solid angle of the observer, $d\Omega_M$, i.e.,

$$n_t^i = M_j^2 \frac{d\Omega_i}{d\Omega_M} \tag{3-13}$$

where the minimum solid angle resolvable by an unaided observer is a constant value,

$$d\Omega_M \equiv 4.09 \times 10^{-8} \text{ Steradians} \tag{3-14}$$

and M_j is the magnification of the aided observer (e.g., binocular aided) The solid angle subtended by the target is computed as:

$$d\Omega_i = a_t^i \left[1/3 \cos \Theta_K + \sin \Theta_K\right] \frac{1}{S_R^2} \tag{3-15}$$

or:

$$d\Omega_i = a_t^i \left[\frac{R_K + 3h}{3S_R}\right] \frac{1}{S_R^2} \qquad (3\text{-}16)$$

where Θ_K is the angle of depression shown in Figure 3-9, a_t^i is the average presented target area for the ith type target, and R_K, S_R, and h are the ground range, slant range, and altitude, respectively. The factor of 3 in Equation 3-16 results from the assumption that the target height is roughly two thirds of its mean lateral dimensions.

b. Target Contrast Effects. The effects of target and background contrast are handled in the same manner as in the Ground Combat Model, with a slight modification to account for the optical slant range. The probability of detecting a single resolvable target subelement with reflectance ρ_t^i against a background of reflectance ρ_b is computed as:

$$\Phi(u) = \int_{-\infty}^{u} e^{-\frac{v^2}{2}} dv \qquad (3\text{-}17)$$

where:

$$u \equiv \frac{50\ C_a^i - 1.0}{0.482} \qquad (3\text{-}18)$$

and the apparent contrast, C_a^i, is expressed as:

$$C^i = C_t^i \frac{1}{1 + \frac{1}{\rho_b}(e^{\beta r'} - 1)} \qquad (3\text{-}19)$$

The intrinsic contrast, C_t^i, in the above equation is given by:

$$C_t^i = \frac{|\rho_t^i - \rho_b|}{\rho_b} \qquad (3\text{-}20)$$

and the optical slant range, r', is related to the altitude, h, and ground range, R_K, by Equation 3-21 (Reference 29).

$$r' = \left(1 + \frac{R_K^2}{h^2}\right)^{1/2} \left(1 - e^{\frac{h}{6610}}\right) 6610 \qquad (3\text{-}21)$$

The optical slant range, r', is used in Equation 3-19 to account for the change in air density as a function of altitude. This means that the quantity and distribution of air along the slant range giving rise to light scattering and absorption is not the same as for a horizontal separation. The difference is accounted for using Equation 3-21. Physically, r' is the horizontal distance which would contain as much air as does the slant range, $(h^2 + R_K^2)^{1/2}$. The effective attenuation coefficient, β, representing light scattering and absorption is defined from the visible range, V_R, as:

$$\beta \cong \frac{3.912}{V_R} \qquad (3\text{-}22)$$

c. Effective Number of Resolvable Subelements. The effective number of resolvable target elements used to determine the probability of recognition or identification as expressed in Equation 3-12 is derived from the assumption that contrast reduction results in a net decrease in the number of resolvable subelements. In equation form this relation is expressed as:

$$\langle n_t^i \rangle = n_t^i \left\{1 - \left[1 - \Phi(u)\right]^{\sqrt{n_t^i}}\right\} \qquad (3\text{-}23)$$

Thus, if only one target subelement is resolvable, the expected probability of detecting this element is given by:

$$\langle n_t^i \rangle = n_t^i \, \Phi(u) \qquad (3\text{-}24)$$

$$= \Phi(u) \qquad (3\text{-}25)$$

and the corresponding recognition probability is given by Equation 3-12. As the apparent target size increases, the number of resolved elements is increased according to Equation 3-23.

2. Subunit Detection Probability. After the probabilities of recognizing the distinct target types in a subunit have been determined, the next step is to compute the probability of detecting and recognizing at least one target within the entire k^{th} subunit given that one is looking

within the subunit area. This expression involves the total number of targets in LOS and the probability of looking at a single target within the subunit. It is expressed as:

$$PD^k = 1 - \prod_i \left[1 - PD^i\left(\frac{\Omega_M^i}{\Omega_K}\right)\right]^{\langle m_i' \rangle} \tag{3-26}$$

where Ω_M^i is the field of the target elements type i in line of sight; i.e.,

$$\Omega_M^i \equiv \text{MINIMUM}\left[\langle m_i' \rangle \bullet d\Omega_i, \Omega_K\right] \tag{3-27}$$

The solid angle subtended by the subunit is given by:

$$\Omega_K = a_S^K \frac{h}{(R_K^2 + h^2)^{3/2}} \tag{3-28}$$

where a_S^K is the ground area occupied by the k^{th} subunit. The probability of looking at a particular target type i is the ratio of Ω_M^i to Ω_K.

3. Single Observer Detection Probability. To obtain the total probability that the j^{th} observer will detect and recognize a target located in one of the subunits, the subunit probabilities, PD^k, are combined with the probabilities that the observer's field of view includes the subunit to obtain, PD^j; i.e.,

$$PD^j = 1 - \prod_k \left[1 - P_L^{jk} PD^k\right] \tag{3-29}$$

The probability of looking is approximated as:

$$P_L^{jk} = \frac{\Omega^{jk}}{\Omega_T^j} \tag{3-30}$$

where Ω_T^j is the field of the j^{th} observer (steradians) and Ω^{jk} is given by:

$$\Omega^{jk} = \text{MINIMUM}\left(\Omega_T^j, \frac{\pi}{2} + \Theta_K\right) \tag{3-31}$$

where Θ_K is the depression angle to the subunit from the observer.

4. Expected Time to Detection. Once the single observer probability of recognizing a target in a single glimpse has been calculated (Equation 3-29) the expected time to detect is obtained by assuming a Poisson distribution as representative of the detection process (refer to Ground Combat Model) and computing the mean time to detect, Δt_M^j, as:

$$\Delta t_M^j = \frac{t_g}{PD^j} \tag{3-32}$$

where t_g is the effective glimpse time. Using this mean time, Δt_M^j, and a random number, RN, between zero and one, the actual time at which a detection occurs is simulated as:

$$t_d^j = \Delta t_M^j \ln\left(\frac{1}{1 - RN}\right) \tag{3-33}$$

This time represents the time at which the j^{th} observer fixates on a particular target. It is measured from the beginning of flight leg, or from the last fixation time simulated during the current flight leg.

5. Detection Decision. The above procedure of computing a time of detection is completed for each observer onboard the aircraft. The minimum simulated detection time for all observers is then selected and compared to the time remaining in the flight leg. If the time remaining in the flight leg exceeds the simulated time to detection, the detection is made. If the detection occurs in the flight leg, the collection trial continues. The assumption is that this time represents the time at which an observer detects something on the ground. The next step in the detection logic is to determine in which subunit the detection is expected to have occurred.

6. Subunit Selection. Using the PD^k values computed for the observer detecting the target, the following sum is formed:

$$S = \sum_{k=1}^{N} \frac{PD^k}{1 - PD^k} = \sum_{k=1}^{N} \overline{PD}^k \tag{3-34}$$

Individual terms in the summation are proportional to the probability that the observer detects only this k^{th} subunit. Thus, a scale is formed between zero and S with N intervals related to detection probabilities. Randomly choosing a number between zero and S and locating the k^{th} subunit such that the condition:

$$\sum_{k=1}^{k_d-1} \overline{PD}^k \leq RN < \sum_{k=1}^{k_d} \overline{PD}^k \tag{3-35}$$

is satisfied, identifies the k_dth subunit as the subunit in which the target has been detected.

7. Identification of Targets in the Subunit. Once an observer has made the initial detection, it is assumed that all the observers onboard will focus their attention on the subunit and search the area for other unmasked targets. This process is modeled by estimating the number of targets detected, recognized, and identified as:

$$\langle m_i'' \rangle = \langle m_i' \rangle \text{ MAXIMUM } \left[PI^{ij=1}, PI^{ij=2}, \ldots \right] \tag{3-36}$$

where $\langle m_i'' \rangle$ is the expected number of ith type target identified and PI^{ij} is the identification probability. It is computed as:

$$PI^{ij} = \int_0^{\langle n_t^j \rangle} \frac{1}{u} \frac{1}{\sigma_I} e^{-\frac{1}{2}\left[\frac{1}{\sigma_I} \ln\left(\frac{u}{n_o^J}\right)\right]^2} du \tag{3-37}$$

where the parameters are as defined on page 3-26. (Note that the parameters n_o^I and σ_I now represent identification rather than recognition thresholds. Values currently in use in the model are taken from Reference 25. The detection curves represented by Equations 3-37 and 3-12 are illustrated in Figure 3-10. Along the horizontal axes of the two upper graphs is the number of resolvable target elements. This quantity is in effect a measure of the closeness of the target object to the observer. For example, a representative tank target of approximately 12 square meters presented area contains about 30 resolvable elements when at a range of 3100 meters and about 80 resolvable elements when viewed at a range of 1800 meters. Thus, if the relative target contrast against the background is large enough to ensure a high probability of detection versus contrast level, then the probability of identifying this object as a tank (not a truck or an APC) at 3100 meters range is about 0.08, while the probability of recognizing the object as a target is much higher, about 0.90, according to the curves in the figure. The last curve in the figure is a plot of the signal-to-noise level required to expect various detection probabilities from MTI radars. For example, a signal-to-noise ratio of about 10 produces a 40 percent chance that the target signatures will be detected by the operator or image interpreter on the processed film.

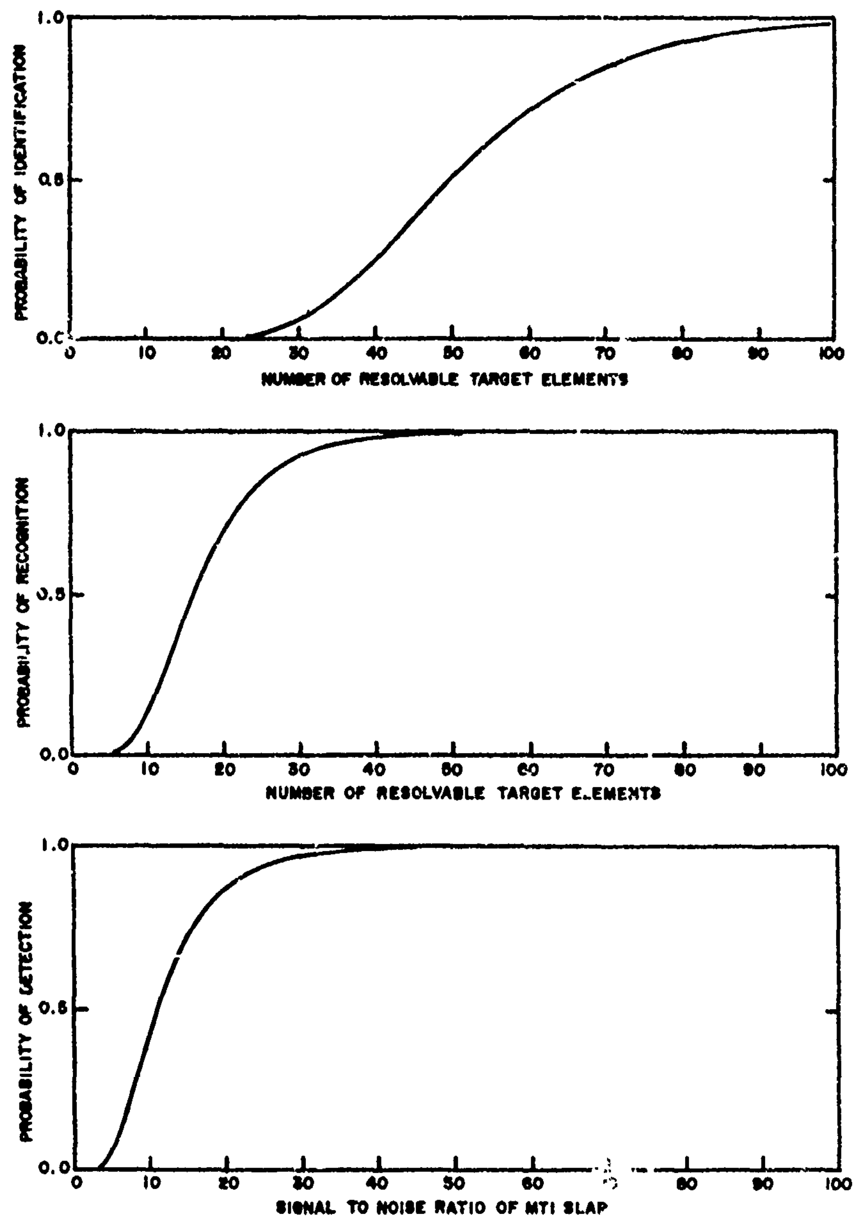


Figure 3-10. Recognition and Identification versus Resolved Target Elements or Signal-to-Noise

8. Invalid Detection Trial. The number of targets identified in Equation 3-36 is always rounded to integer values at the 0.5 level. If, in this rounding process, zero entries should result for all target types, the detection trial is declared to be an invalid sighting. This subunit is dropped from the potential target list, the time required for the detection is subtracted from the time remaining in the flight leg, and the detection trial is repeated for subunits remaining in the potential target matrix. The iteration procedure continues until either a valid sighting is made or the flight leg flight time is exhausted.

9. Positive Target Identification Trial. If targets have been identified, they are tallied and a sensing report is prepared. This report contains the number and target types identified, estimated activity of the subunit, direction of movement, estimated time of detection, and estimated location.

a. Estimated Time of Detection. An estimation of the time of detection is obtained by adding to the simulated detection time an estimate of the time required to identify the targets reported, Δt_I. This time is computed in the following manner:

$$\Delta t_I = t_g \sum_{i=2}^{9} \langle m_i'' \rangle + t_g[1 + \ln (\langle m_i'' \rangle + 3)] \qquad (3\text{-}38)$$

For each nonpersonnel target identified, a time to identify of t_g is added; for personnel targets a time of t_g plus $t_g \ln(\langle m_i'' \rangle + 3)$ is added. The logarithm of $\langle m_i'' \rangle + 3$ is used to account for the fact that if a large number of personnel are present, discrete identification of each person is not made. Rather, the detection process would count much larger groups. Thus, the approximation merely reflects the fact that for numbers much greater than 20, the time to identify is not increasing linearly with $\langle m_i'' \rangle$. The time of detection entered in the sensing report is given by:

$$t_R = \Delta t_M^i + \Delta t_I \qquad (3\text{-}39)$$

b. Estimated Subunit Location. The LOH mission unit estimates the target location using a simulated error approximation as follows. Using the subroutine ENORM a random normal deviate is computed and multiplied by the input data value of σ_{CEP} for the LOH collection system. The location error is entered as a CEP error defined as the location error in meters expected 50 percent of the time. This data entry is converted to a normal distribution with variance σ_{CEP} using the relation:

$$\sigma_{CEP} = \frac{CEP}{(2\ln 2)^{1/2}} \qquad (3\text{-}40)$$

Using a random angle, ϕ_R, between zero and 2Π, the estimated coordinates of the subunit are computed as:

$$x_{est} = x_{su} + \text{ENORM}(\sigma_{CEP}) \cos(\phi_R) \qquad (3\text{-}41)$$

and

$$y_{est} = y_{su} + \text{ENORM}(\sigma_{CEP}) \sin(\phi_R) \qquad (3\text{-}42)$$

(h) Reporting the Detection. The sighting is reported using the standard sensing report format described previously. Two sensing report copies are sent into the Intelligence and Control Model. One represents the reporting to the fire support channel and the other is the reporting representing entry of the sighting information into intelligence channels. The time delays representing the elapsed time until the reports arrive at their respective destinations are part of the constant data input.

(i) Sensing Report History. To facilitate overlapping of look sectors, each airborne mission unit maintains a current file of sensing reports previously sent in during the flight. This report history is used to screen the potential subunit target of subunits that have been reported in previous flight legs.

(6) Mohawk OV-1D Reconnaissance Mission (RECON2):

(a) General. The reconnaissance mission portrayed in RECON2 is representative of the Mohawk OV-1D type aircraft equipped with a side looking airborne radar (SLAR) with a moving target indicator (MTI) detection capability. The logic is adequate to simulate the capability of the system with onboard film processing and imagery interpretation or with a real time data link to a ground sensor terminal (GST) and image interpretation facility. In either case the sensor onboard which is of primary concern is the SLAR MTI radar. The following discussion deals with the DSL order, flight path, range gate control, and detection logic.

(b) Flight Geometry:

1. DSL Flight Path. The flight path flown by the Mohawk unit is specified in the DSL order by a set of endpoints. The flight intervals are divided into flight legs to establish collection trial events. These flight leg lengths are fixed at approximately 90 seconds' flying time in the current model operation. The exact length is not critical but is related to computer running time and level of resolution of units being detected.

2. DSL Control Code Data. To establish the area on the ground that is covered by the radar beam the range and delay settings are input through the DSL order Control Code Data. The first character of the Control Code is an M and identifies the mission type. The second character is

used to set the range and delay of the SLAR MTI sensor package during the RECONNOITER order. The allowable set of range and delay parameters is illustrated in Figure 3-11 in the included table where the values of RANGE1, RANGE2, RANGE3, and DELAY are constant data inputs. The third character is either an R, L, or B and indicates the direction in which the radar is pointing (i.e., either to the right (R), to the left (L), or to both (B) sides of the current flight leg).

(c) Unit Search Geometry:

1. Nominal Screening Box. The geometry used to screen potential units for possible location within the coverage area of the radar is also shown in Figure 3-11. The nominal search radius is computed from the range setting, R_G, and the flight leg length R_F, as:

$$R_S = \frac{(R_G{}^2 + R_F{}^2)^{1/2}}{2} + 4000 \text{ meters} \tag{3-43}$$

This is the radius used in the SEARCH routine to identify enemy units in the circular region. These units are further screened to eliminate any unit that is not within a coarse screening box whose sides are 4000 meters outside of the boundaries of the actual coverage box.

2. Line of Sight Screening. Each unit inside of the 4-kilometer box is checked for line of sight conditions using the Dominant Mask Function Model's LOS routine. The decision is a yes or no criterion and is applied to all the targets in the unit. Only those units deemed in line of sight are retained for the detection trial.

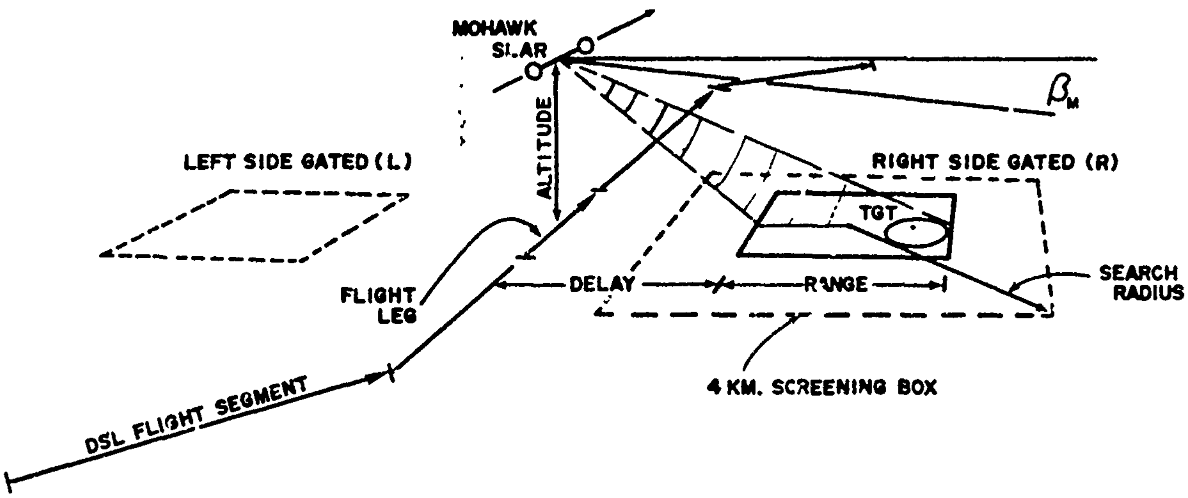
3. Moving Unit Screen. To be vulnerable to MTI radar the unit must be moving. Stationary units are dropped from further consideration.

(d) Detection Trial Logic. The radar model used in this routine is an adaptation of the radar equation of References 25 and 31. The signal-to-noise ratio (S/N) at the MTI radar receiver is computed for each target type and is translated to an expected detection and recognition probability as a function of $(S/N)_i$. The radar equation parameters, signal-to-noise calculation, and target type identification logic are discussed in the following subparagraphs.

1. Signal-to-Noise Calculation.

a. Radar Equation. The $(S/N)_i$ ratio for the i^{th} type target is computed using the radar equation from References 25 and 31:

MOHAWK OV-1D SLAR MTI RANGE & DELAY SETTINGS



SLAR MTI SETTINGS

Second Character of Control Code	Delay Setting	Range Setting
0	0 x DELAY	RANGE1
1	1 x DELAY	RANGE1
2	2 x DELAY	RANGE1
3	3 x DELAY	RANGE1
4	4 x DELAY	RANGE1
5	5 x DELAY	RANGE1
6	6 x DELAY	RANGE1
A	0 x DELAY	RANGE2
B	1 x DELAY	RANGE2
C	2 x DELAY	RANGE2
D	3 x DELAY	RANGE2
E	4 x DELAY	RANGE2
F	5 x DELAY	RANGE2
Z	0 x DELAY	RANGE3

Figure 3-11. Mohawk SLAR Range Gating

$$(S/N)_i = \frac{P_t \cdot \lambda_r^3 \cdot PRF \cdot G_{ae}^2 \cdot \tau_{ra}^2 \cdot \tau_{sf} \cdot \tau_{rf}}{(4\pi)^3 \cdot P_{nr} \cdot D_x \cdot V_g \cdot S_R^3} \sigma_t{}^i$$

$$= C_{SN} \ \sigma_t{}^i \qquad (3\text{-}44)$$

where the variables are defined as follows:

P_t = pulse power transmitter (watts)

λ_R = radar wavelength (meters)

PRF = pulse repetition frequency

P_{nr} = noise power of receiver (watts)

D_x = effective linear azimuthal resolution of synthetic antenna (meters)

V_g = flight speed (meters per second)

G_{ae} = antenna gain

τ_{ra} = rain loss factor

τ_{sf} = signal filter loss factor

τ_{rf} = signal filter loss factor with rain

S_R = slant range (meters), perpendicular to flight leg

$\sigma_t{}^i$ = target radar cross section of i^{th} target ($meters^2$).

The antenna gain factor is computed as:

$$G_{ae} = \frac{\cos^{1/2}\beta}{\cos^2\beta} \ \frac{\cos^2\beta_m}{\cos^{1/2}\beta_m} \ e^{\ 0.23025 \ G_o} \qquad (3\text{-}45)$$

where:

G_o = antenna gain in db

β = depression angle of target

β_m = depression angle of antenna.

The rain loss factor τ_{ra} is computed as:

$$\tau_{ra} = e^{-0.0023025(A_a + A_r)\cdot(2S_R)} \qquad (3\text{-}46)$$

where:

A_r = rain absorption coefficient (db/km) for weather precipitation (fog, light rain, or heavy rain)

A_a = atmospheric absorption coefficient (db/km).

The rain signal filter loss factor, τ_{rf}, is given by:

$$\tau_{rf} = e^{-2.3025\ L_{rf}} \qquad (3\text{-}47)$$

where L_{rf} is the signal loss in db due to rain filtering. The clutter and normal signal filtering loss factor, τ_{sf}, is given by:

$$\tau_{sf} = e^{-2.3025\ L_{sf}} \qquad (3\text{-}48)$$

Combining all of the losses above, a total loss factor, τ', is obtained:

$$\tau' = e^{-0.23025[0.002S_R(A_a + A_r) + L_{sf} + L_{rf}]} \qquad (3\text{-}49)$$

b. (S/N) for Target Type. For a fixed set of conditions in a detection trial the $(S/N)_i$ ratio for the i^{th} type moving target is given by:

$$(S/N)_i = C_{SN} \cdot \sigma_t{}^i \qquad (3\text{-}50)$$

where σ_t^i : the target radar cross section, is given by:

$$\sigma_t{}^i = \Gamma_t{}^i \cdot a_t{}^i\left(\frac{R_k + 3h}{3S_R}\right) \qquad (3\text{-}51)$$

and $\Gamma_t{}^i$ is the i^{th} target type's radar reflectance and $a_t{}^i$ is the mean presented area as discussed in the RECON1 logic.

2. Target Detection Probability. Using the (S/N) ratio for each target type the detection probability, PD^i, is arrived at using the relation:

$$PD^i = (1 - M) \frac{1}{\sigma_{SN_o}} \int_0^{(S/N)_i} \frac{1}{u} e^{-\frac{1}{2}\left[\frac{1}{\sigma_{SN_o}} \ln\left(\frac{u}{(S/N_o)}\right)\right]^2} du \qquad (3\text{-}52)$$

where:

M = fraction of unmasked detectable targets missed by image interpreter

$(S/N)_o$ = signal-to-noise ratio required for 50 percent detection and identification threshold

σ_{SN_o} = measure of variance of $(S/N)_i$ level about $(S/N)_o$ for 50 percent detection level in log domain.

3. Subunit Detection Logic. Once the individual detection probabilities for the i^{th} target types are known, the total probability of detection for at least one target within the k^{th} subunit is computed as:

$$PD^k = 1 - \prod_i (1 - PD^i)^{\langle m_i' \rangle} \qquad (3\text{-}53)$$

To establish a detection decision, the value of PD^k is compared with a random number between zero and one; and if the random number is less than PD^k, a detection is made. The estimate of the number of targets detected is derived from the expected values as:

$$\langle m_i'' \rangle = m_i \cdot PD^i \qquad (3\text{-}54)$$

and is rounded to integer values with a 0.5 roundoff factor.

4. Time of Detection for Subunit. The time at which the unit was recorded is determined by the projection of the subunit's perpendicular distance onto the flight leg. The intersection point is used to establish the time of overflight, t^k_{of}. Using this time and adding a film processing delay, Δt_{fp}, and a detection delay, Δt_{dd}, the time of detection, t^k_d, is given by:

$$t^k_d = t^k_{of} + \Delta t_{fp} + \Delta t_{dd} \qquad (3\text{-}55)$$

All subunits are processed in this manner and stored in a potential target matrix until the last subunit in the unit has been accounted for.

(e) Subunit Preprocessing. Upon completion of the individual collection trials on the subunit of a unit, the subunits detected are aggregated to represent the combined sensing of the entire unit. The actual time of estimated detection and estimated coordinate locations are determined in the following manner:

1. Unit Detection Time. The simulated time of detection for the unit is established by selecting the subunit that was last to be detected and using this subunit time as representative of the earliest time at which all the subunits (i.e., combined unit) were detectable.

2. Unit Coordinate Locations. The coordinate location computed for the combined subunits is obtained by determining a weighted average of the subunit location. The weighting factors are the number of targets detected in the individual subunits. In equation form, the unit's coordinates are expressed as:

$$x_u = \frac{\sum_{k=1}^{N_k} X_S{}^k \sum_{i=1}^{N_i^k} \langle m''_{ik} \rangle}{\sum_{k=1}^{N_k} \sum_{i=1}^{N_k^i} \langle m''_{ik} \rangle} \tag{3-56}$$

$$y_u = \frac{\sum_{k=1}^{N_k} Y_S{}^k \sum_{i=1}^{N_i^k} \langle m''_{ik} \rangle}{\sum_{k=1}^{N_k} \sum_{i=1}^{N_k^i} \langle m''_{ik} \rangle} \tag{3-57}$$

where:

$X_S{}^k$, $Y_S{}^k$ = location of the k^{th} subunit

$\langle m''_{ik} \rangle$ = number of targets of type i detected in the k^{th} subunit

N_k = number of subunits detected

N_k^i = number of target types in the subunit.

3. Unit Estimated Location. The target location errors in the collection system are introduced into the unit location (X_u, Y_u) computed above in the same manner as was done for subunits in the logic of RECON1; i.e.:

$$x_{est} = X_u + \text{ENORM}\ (\sigma_{CEP})\ \cos(\phi_R) \qquad (3\text{-}58)$$

$$y_{est} = Y_u + \text{ENORM}\ (\sigma_{CEP})\ \sin(\phi_R) \qquad (3\text{-}59)$$

where ϕ_R is defined as before and σ_{CEP} is now the location error of the Mohawk SLAR MTI sensor system.

(f) Reporting Detection. The detection process described above is iterated until all units in the coverage sector have been checked. To simulate the identification of and reporting of sightings, a time delay is added to each sensing report produced representative of the elapsed time until the reports arrive at their respective destinations. In addition to the delays representing film processing, identification time, and report preparation and transmittal, a processing and reporting queuing delay is also simulated. As successive targets are overflown and recorded on film the potential for exceeding the imagery interpretation and reporting capacity exists if reports are not queued. The target units to be reported are selected in their order of detection during the overflight time. The first sensing report is sent in with a delayed event time of:

$$\Delta t^{1=1} = t_{of}^{1=1} + \Delta t_{SR} + \Delta t_{RPT} \qquad (3\text{-}60)$$

where:

t_{of} = time of overflight

Δt_{SR} = time to process film and identify targets

Δt_{RPT} = time for report to be entered into respective fire support or intelligence channel.

Subsequent targets identified in this search region are sent in at even time delays given by:

$$\Delta t^{1} = \text{MAXIMUM}\left[(t_{of}^{1} + \Delta t_{SR} + \Delta t_{RPT}),\ \left(\Delta t^{1-1} + \Delta t_{RPT} + \frac{\Delta t_{SR}}{n_i}\right)\right] \qquad (3\text{-}61)$$

where n_i is the number of image interpreters available to process the film. Thus, no two reports from sightings in this collection trial will reach the same communications node with time separations of less than $\Delta t_{RPT} + \Delta t_{SR} \div n_i$.

(7) Air Force Reconnaissance Mission (RECON3):

(a) General. RECON3 simulates the performance of Air Force reconnaissance and surveillance missions. The sensor types currently portrayed in the model are the visual observer and the various camera types. Information obtained in these reconnaissance missions is made available to each division level intelligence center after appropriate delays for film processing and handling, image interpretation, report processing, and transmittal activities. The following discussion is concerned with the flight control, sensor load, and detection logic simulated within the submodel.

(b) Flight Geometry. The flight geometry of RECON3 is similar to that described in RECON2. One difference is the determination of the flight leg length. In RECON3, the flight leg is set as:

$$F_{LEG} = \text{MINIMUM } [5000,\ 5h] \text{ meters} \qquad (3\text{-}62)$$

to ensure adequate coverage of the area by the onboard cameras.

(c) Sensor Load Combination. The particular sensor load onboard is specified in the DSL order by the load combination index in the fourth character of the Control Code. The various load combinations are established in the pregame data preparation phase.

(d) Target Unit Search Geometry:

1. Visual Observers. The sensitive look sector for each flight leg is identical to that used in the LOH, with the exception of the center being projected forward at a 60° depression angle from the aircraft.

2. Camera System Search Geometry. All camera systems use a search box with a dimension in the flight direction equal to the flight leg and a lateral dimension set by the field of view of the camera system. The centers of the respective search boxes for the collection trial are set based on the camera's depression angle and direction of camera (i.e., forward oblique, vertical, left side oblique, or right side oblique). The screening logic used to identify potential targets is identical to that performed by the Mohawk except that the stationary units are included as potential targets for cameras.

(e) Detection Trial Logic. The detection trial logic used to simulate the detection, identification, and reporting of visual sightings is identical with the logic used in RECON1. For camera systems, the generation of sensing reports is similar to the logic of the Mohawk routine, RECON2, with exceptions for the sensor type differences and the delay times required for

film processing and image interpretation following completion of the mission. The following discussion refers to cameras only.

1. Subunit Targets. The individual detection decisions are again based on subunit size targets. Whereas the line of sight screen is applied to the unit as a whole, the target detection calculations are applied to the separate subunits within the unit. Once these detection decisions on the subunits have been made, the subunit within the units that have been identified are aggregated or preprocessed to represent the actual photo interpretation identifications of targets. The simulation is patterned after the camera model of Reference 25.

a. Camera Resolution at Target Contrast Level. The simulated ground resolution of the camera as given by Reference 25 is:

$$R_c^i = R_{max}\left[0.8M_a^i + 0.2\left(1 - e^{-50M_a^i}\right)\right] \quad (3\text{-}63)$$

where R_{max} is the operational camera resolution and M_a^i, the apparent contrast modulation, is expressed in terms of the apparent contrast, C_a^i, Equation 3-19, as:

$$M_a^i = \left|\frac{C_a^i - 1}{C_a^i + 1}\right| \quad (3\text{-}64)$$

This resolution factor R_c^i is computed for each target type in the subunit.

b. Camera Scale Factor. To convert the camera resolution on film, R_c^i, to the equivalent ground resolvable distance, D_R^i, in the present mission, the camera scale factor, S_c is determined for each camera type as follows:

Vertical Frame

$$S_c = \frac{h}{f} \quad (3\text{-}65)$$

where f is the camera focal length.

Side Oblique Frame

$$S_c = \frac{h}{f}\sin\Theta_D + \frac{R_k}{h}\cos\Theta_D \quad (3\text{-}66)$$

where:

R_K = ground track range to the target

Θ_D = depression angle of camera.

Front Oblique Frame

$$S_c = \frac{h}{f\sin\Theta_D} \tag{3-67}$$

Panoramic Frame

$$S_c = \frac{h}{f\sin\Theta_D}\left[1 + \left(\frac{R_K\sin\Theta_D}{h}\right)^2\right]^{1/2} \tag{3-68}$$

c. Ground Resolved Distance. Using the camera resolution, R_c^i, and the scale factor, S_c, the ground resolved distance for this camera type is given by:

$$D_R^i = S_c R_c^i \tag{3-69}$$

Using D_R^i the number of resolvable target subelements on the exposed film is expressed as:

$$n_t^i = \frac{a_t^i}{(D_R^i)^2} \tag{3-70}$$

with a_t^i the mean presented target area of the i^{th} target type.

2. Probability of Identification of Target Type. The probability of identifying a target type i is computed for each type as:

$$PD^i = \frac{1-M}{\sigma_J} \int_0^{n_t^i} \frac{1}{u} e^{-\frac{1}{2}\left[\frac{1}{\sigma_I} \ln\left(\frac{u}{n_o^I}\right)\right]^2} du \qquad (3\text{-}71)$$

where:

M = fraction of unmasked identifiable targets missed by the photo interpreter

n_o^I = median number of resolved target subelements required for 50 percent identification confidence level

σ_I = variance of n_t^i about n_o^I for the 50 percent threshold level in log domain

3. Subunit Detection Criteria. The combined probability of detecting and identifying a subunit is established as before; i.e.:

$$PD^k = 1 - \prod_i (1 - PD^i)^{\langle m_i' \rangle} \qquad (3\text{-}72)$$

where $\langle m_i' \rangle$ is the number of i^{th} type targets in LOS. Again a random number, RN, between zero and one is compared with PD^k to simulate a detection.

4. Targets Detected. If the subunit is detected, the expected number of target elements identified is given by:

$$\langle m_i'' \rangle = \langle m_i' \rangle PD^i \qquad (3\text{-}73)$$

(f) Subunit Preprocessing. The preprocessing of subunits follows the same procedure used in RECON2 to establish unit sensing reports. The number of targets for each target type is obtained by summing the targets of the individual subunits.

(g) Unit Location Errors. Location estimates are established as in RECON1 and RECON2 using a σ_{CEP} characteristic of the Air Force reconnaissance collection system and camera type.

(h) Reporting of Identified Targets. The process that is simulated in identifying the target unit is the process that would normally occur after the reconnaissance aircraft has returned to base or ejected the exposed film and after the film has been processed and delivered to the image interpretation facility. Thus, the processing of the film will not actually occur until later during the simulated game period. If the reconnaissance mission is lost, the information will be lost. To allow the model to maintain

The elevation of this swept area is zero for ground units but reflects the specified altitude of air units.

(c) Detection Vulnerability Critera. CCOLLM uses several criteria to determine whether the predicted segment of move could possibly be detected. These criteria must be met before a collection trial event is scheduled.

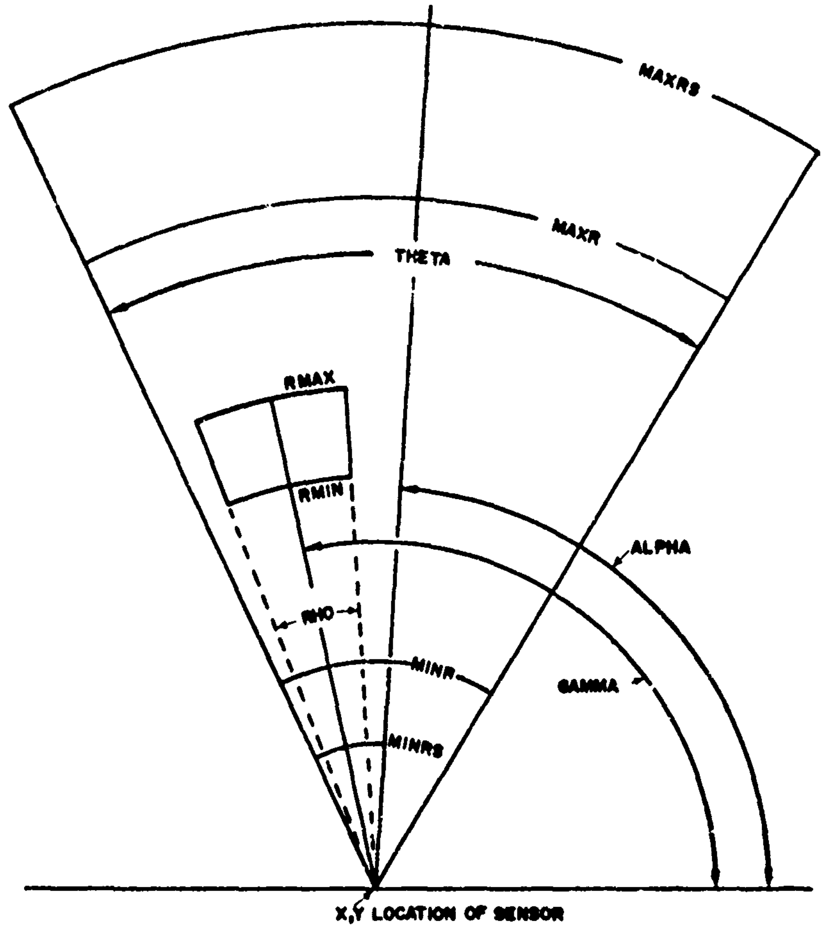
1. Collection System Status. The primary criterion is the availability of the particular site. If a sensor system is moving or otherwise inoperable it will not be considered.

2. Range and Orientation. The secondary criterion is the existence of overlap between the rectangular area swept by the moving unit on this move segment and the assigned search sector of a radar of the active area of an UGS field. In the case of aircraft, altitude is also considered so that the aircraft must be within the current search volume envelope of the air defense radar.

3. Line of Sight. If the collection system is an MTI or air defense radar site, line of sight with the potential target must exist. The calculation of line of sight uses the DMF calculation, and the LOS function returns a yes or no condition as to existence of line of sight. The DMF calculation is described in Chapter 2.

4. Radial Unit Velocity. MTI ground surveillance radars generally cannot distinguish the moving unit from background unless the unit moves toward or away from the radar at greater than some threshold speed. That component of the velocity of the unit which is toward or away from the radar is the radial velocity of the unit. The threshold value for each radar type is input in the constant data for the radar. Actual radial velocity of the unit is calculated by the model and must equal or exceed the threshold for a detection to be possible.

5. Time to Sweep Unit. For MTI ground surveillance radars there must be time for the radar to scan through enough of its assigned search sector to sweep the moving unit while it is in the search sector during the current move segment. With the radar in an autoscan mode the position of the radar beam at the time the moving unit enters the search sector or starts its move segment from a position inside the search sector may in reality vary from exactly on the unit to approximately one whole search sector away (in scan) from the unit. The model assumes that on the average the beam can be expected to have to travel one half of a full search sector before it sweeps the unit. The model calculates this average time using the size of the assigned search sector and the beam width and depth. Figure 3-12 outlines the geometry within which this calculation is made. The currently assigned search sector of the radar has an inner radius of MINR and an outer radius of MAXR, with a sector angular width of THETA. Within this search sector the active portion of the radar beam has an inner radius of RMIN, an outer radius of RMAX, and a constant angular width of RHO. The model assumes that the active beam center



SEARCH GEOMETRY FOR GROUND MTI RADAR

MAXRS = Maximum range capability of sensor
MINRS = Minimum range capability of sensor
MAXR = Maximum range of currently assigned search sector
MINR = Minimum range of currently assigned search sector
RMAX = Current upper range gate of radar beam
RMIN = Current lower range gate of radar beam
ALPHA = Center azimuth of currently assigned search sector
THETA = Width of currently assigned search sector
GAMMA = Current center azimuth of radar beam
RHO = Current width of radar beam

Figure 3-12. Search Geometry for Ground MTI Radar

sweeps the entire width of search sector, THETA, with the beam depth (between RMIN and RMAX) held constant for each angular sweep. At the end of one angular sweep, the model assumes that the beam is stepped by one constant beam depth increment for the next angular sweep. The angular rate of beam sweep (angular search rate) is a game input constant for the radar type, as is beam depth and angular width, therefore, the time to search the entire sector is the time to make one angular sweep, multiplied by the number of beam depths between inner and outer radii of the search sector. The average time delay to reach the moving unit is then half the time to search the entire sector. This average time to sweep the unit must be less than the predicted move segment time, less any portion of the move segment time outside the search sector, which is also calculated when the move segment enters the fan.

(d) Timing of Vulnerability to Detection. When Subroutine CCOLLM is activated and the criteria for vulnerability to detection are met, the time at which vulnerability to detection starts for this move segment of the moving unit and this sensor is the basis for scheduling a collection trial event. The time at which vulnerability to detection starts is based on the time at which CCOLLM is activated, if the start of this move segment is inside the search sector fan of a radar sensor or is inside the sensitive area of an UGS field. Otherwise, start of vulnerability time is based on when the moving unit enters the fan or field. Determination of the coordinates and time at which entry occurs differs slightly according to sensor type.

1. MTI Ground Surveillance Radar. For MTI ground surveillance radars, the coordinates at which the moving unit is considered to enter the assigned search sector fan are determined by the line joining the start and end coordinates of the move segment and by the center of the moving unit, versus the search sector fan, which is defined by an outer radius, an inner radius, and two sides radial from the radar The fan may be entered from either arc or either side. The size and shape of the moving unit is not considered in this determination since in most cases, it is assumed, the search sector will be relatively large compared to unit size. The time of fan entry is derived from the coordinate point of entry, in terms of the fraction of move segment traveled to entry, by relation to the predicted time of travel on this move segment. The time of fan entry is then added to the average time for the scanning radar beam to reach and sweep the unit to yield the time at which vulnerability to detection is considered to start.

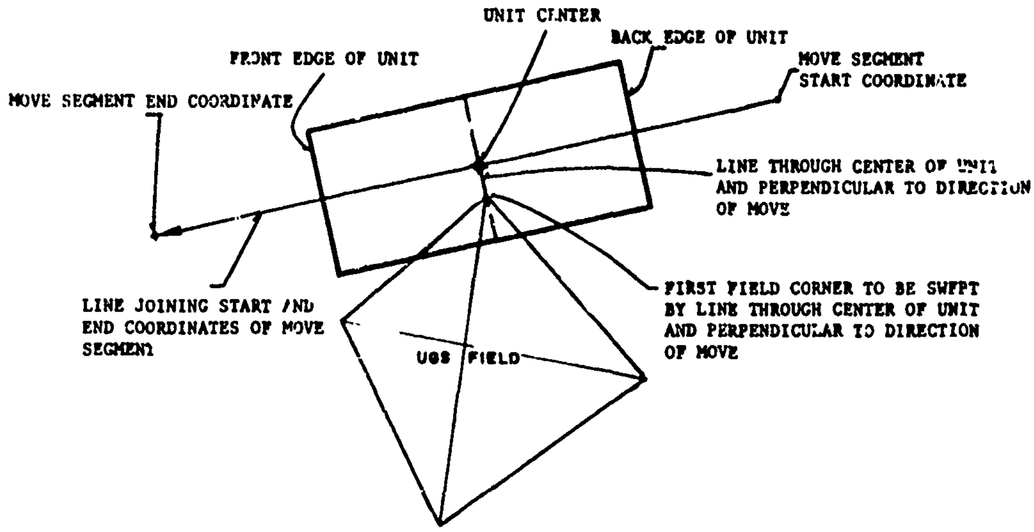
2. Air Defense Radar. For air defense radar, the x, y coordinates at which the air unit is considered to enter the search envelope are determined in a manner essentially the same as for MTI ground surveillance radars, except that for air defense radars the difference in altitude between aircraft and radar, and the vertical search sector of the radar, enter into the calculation. These factors affect the outer and inner radius of the horizontal search sector for this target. No scan time adjustment is made for air defense radar.

3. UGS Field. For an UGS field, the size of the rectangle representing the moving unit is explicitly considered, since unit size may easily exceed UGS field size. A series of geometric tests is necessary to determine if overlap occurs. With UGS fields, the point of entry to the field is usually represented by the first field corner to be swept over by a line representing the width of the moving unit. This line passes through the center of the moving unit and is perpendicular to the direction of move. (See top part of Figure 3-13.) If the field is relatively large, however, and the moving unit does not first sweep over a field corner, the point of entry is determined by the first side or diagonal of the field that is intersected by the line joining the move segment start and end coordinates. (See lower part of Figure 3-13) In both cases the time at which vulnerability to detection is considered by the model to begin is determined by the entry point, which is related to the position of center of the moving unit during its travel on the move segment. These same steps apply if the move segment starts within the UGS field.

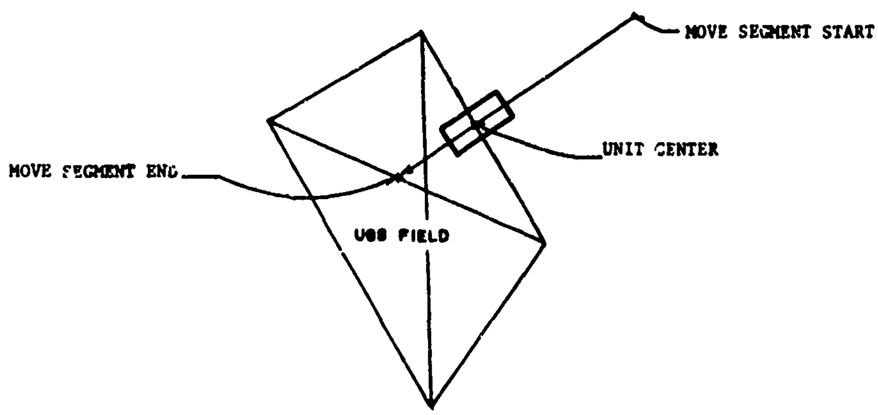
4. Scheduling of Collection Trial. When the criteria for vulnerability to detection are predicted to be met, and the time at which vulnerability is considered to begin is predicted for this move segment and this sensor, CCOLLM proceeds to schedule a collection trial for this sensor. Scheduled time is the time at which vulnerability is considered to begin.

(e) Collection Trials for Moving Targets:

1. General. Collection trials for moving targets versus stationary sensors are performed by Subroutine COLLECT. A collection trial occurs at a time scheduled by Subroutine CCOLLM, after that routine has predicted that a possibility will exist for a specific sensor site to detect a specific moving unit during a given segment of its move course. The collection trial determines whether collection occurs and, if so, what information is collected by the sensor under the current circumstances of this sensor-unit pair. If collection occurs, a sensing report is sent to the intelligence analysis center having direct communication with this sensor. Subroutine COLLECT is primarily concerned with the capabilities of a given sensor at a specific range from the moving unit to detect, recognize, and identify certain items within that unit, to locate that unit, to quantify the number of items identified, and thus to provide information necessary to issuance of a sensing report useful for purposes of fire support, general intelligence, or both. COLLECT does not employ separate probabilities of detection, recognition, identification, and location. Rather, COLLECT treats these capabilities in the aggregate, using a single probability of "collection of an individual item" of the item category being considered, with the process repeated for each category. The probability of "collection of an individual item" value is interpolated from input data supplied individually for each item category to be considered by each sensor. For a collection report to be issued, a threshold probability value must be exceeded in at least one item category. No distortions of information, spurious/false detections (false alarms), or false targets are deliberately simulated by the current model.



UNIT POSITION AT TIME FIRST FIELD CORNER IS SWEPT BY LINE THRU CENTER OF UNIT AND PERPENDICULAR TO DIRECTION OF MOVE



UNIT POSITION AT TIME UNIT CENTER CROSSES FIRST SIDE OR DIAGONAL OF UGS FIELD

Figure 3-13. Entry of UGS Field

2. Prerequisite Conditions for Trial Execution. For the scheduled collection trial to be executed, certain prerequisite conditions must exist. In all cases, the sensor site must be operational and available (not otherwise occupied) for this trial to occur. The current location of the moving unit is established, since its move may have been interrupted by intervening events. In the case of radars, the current location of the moving unit must be within the minimum and maximum ranges of the radar. The current location is some fraction of the way along the most recently established move segment and is derived as follows:

$$X = XACT + F \cdot (MEVTX - XACT) \quad (3\text{-}74)$$

$$Y = YACT + F \cdot (MEVTY - YACT) \quad (3\text{-}75)$$

where:

X = x coordinate of current location

Y = y coordinate of current location

XACT = most recent start of move segment x coordinate

YACT = most recent start of move segment y coordinate

MEVTX = most recently predicted end of move segment x coordinate

MEVTY = most recently predicted end of move segment y coordinate

F = fractional portion of the most recent move segment, based on time data, as follows:

$$F = (T_{now} - T_{segend} + DELT) / DELT \quad (3\text{-}76)$$

where:

T_{now} = Time now

T_{segend} = Predicted end time of most recent move segment

DELT = Predicted travel time interval of most recent move segment.

3. Target Elements Considered. The target types within the moving unit that are to be tried for collection depend on the type of sensor. In all cases, a tally is made of the number of items currently on hand in the moving unit in each type to be considered. Personnel are considered as a target type by all sensors, but only those personnel who are dismounted and thus susceptible to detection as individuals are counted.

a. MTI Ground Surveillance Radar. For MTI radar, eight target types are considered for collection. The eight types are as follows:

- Dismounted personnel
- Tanks
- APCs and APC-like vehicles
- Artillery tubes
- Artillery missiles
- Air defense guns
- Air defense missiles
- Other vehicles not classified above.

b. UGS Fields. For UGS fields, only three target types are tallied and tried for collection. Before collection the tallied number of items is multiplied by the percent of the moving unit width that was predicted in CCOLLM to sweep over the UGS field. After collection but before preparation of the sensing report, the collected values in the two equipment categories are partly rearranged into three equipment categories defined the same way as for MTI radar. The rearrangement grossly simulates some evaluation by the UGS field monitor and facilitates later use of the sensing report. The categories and rearrangement rules are as follows:

Tally and Collection	Sensing Report
1. Dismounted personnel	1. Dismounted personnel
2. All wheeled vehicles	2. Tanks (1/3 tracked vehicles collected)
3. All tracked vehicles	3. APCs and APC-like vehicles (1/3 tracked vehicles collected)
	4. Other vehicles not classified above (all wheeled vehicles collected)

c. Air Defense Radar. For air defense radar, only aircraft are considered, with no modification of the tallied number before collection trial. This brings to nine the total number of target types provided for in the uniform sensing report format.

4. Interpolation and Use of Probability of "Collection of an Item":

a. Interpolation. For radars, linear interpolation between the input values* at the nearest two range points to the actual radar-to unit range provides the probability of "collection of an item" for the given item or target type. The four range points are peculiar to the particular sensor and represent the minimum and maximum range capability of the radar (all items) with two intervening points. The first intervening range point represents the approximate range at which capability against the specific item begins to fall off rapidly, an approximate break point (See Figure 3-14). The second intervening point represents the approximate range at which capability against the specific item falls to either a relatively low probability or zero, as appropriate to the circumstances. For UGS fields, no interpolation is necessary for range. The field as a whole is treated as the sensor. The probabilities of "collection of one item" for each of the three target types considered by UGS fields, are constants. Each constant (limited within the model to a maximum value of 1.0) is the ratio of the sum of the areas within detection radius (for this item type) of each individual UGS device in the field, divided by the total area of the field. Field area is defined by four corner coordinates. (To facilitate calculation of field area, the shape of the field must be a convex quadrilateral.)

b. Use. The specific probabilities of "collection of an individual item" are used in two ways. One way determines whether anything is collected; and the other way determines how many targets are essentially detected, recognized, and identified in each item category.

(1) Collection Decision. To determine whether collection occurs and whether any sensing report will result from this collection trial, the probability of not collecting any items is calculated for each category considered as follows:

$$PND^i = (1 - PD^i)^{\langle m_i \rangle} \qquad (3\text{-}77)$$

where:

PND^i = probability of not collecting any items in i^{th} category

PD^i = probability of "collecting an individual item" of i^{th} type (an individual item is one item in isolation from others)

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* Input values should be consistent with the frequency of activation of CCOLLM. This frequency is essentially determined by terrain cell size. The converse of this frequency tends to represent the duration of exposure of the unit to any sensor within range.

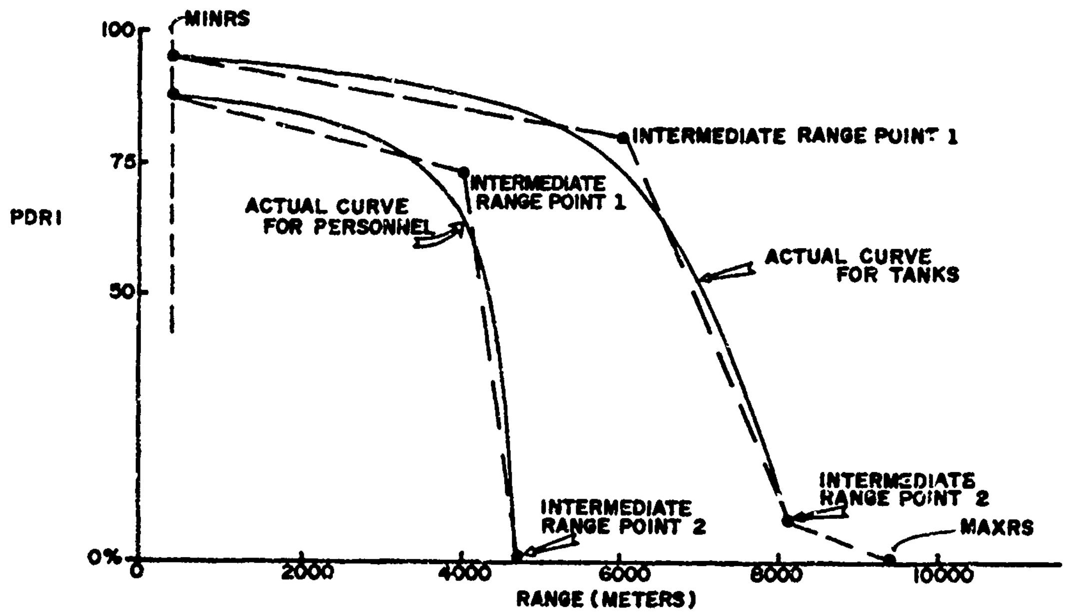

Figure 3-14. Radar Probability of Collection Curves (MTI Ground Radar)

m_i' = applicable number of targets in line of sight.

When all categories have been considered, if the maximum value of one minus PD is less than 0.001, the collection trial of the sensor-unit pair ends, and no sensing report is generated. Otherwise, a determination is made of whether any items are collected in each category. Here, PD^i is compared with a random value from a uniform distribution between zero and one. If the random value is greater than PD^i no collection is recorded in this category.

(2) Number of Items Collected. The number of items collected in any category for entry in the sensing report is determined as follows:

$$m_i'' = m_i' \; PD^i \qquad (3\text{-}78)$$

where:

m_i'' = number of items collected in i^{th} category

m_i' = applicable number of items in line of sight in i^{th} category

PD^i = probability of "collecting an individual item" of i^{th} type.

(f) Location of Target Unit. The actual location of the moving target unit is based on the current unit location at time of detection, the percent of total targets detected in the unit, the rectangular area of the unit, and the location errors inherent in the collection systems sensor(s). The unit's estimated location, X_{est}', Y_{est}', is determined by first estimating the maximum error expected in the width and depth dimensions as:

$$E_w = f^{1/2} \, W_u \qquad (3\text{-}79)$$

and:

$$E_d = f^{1/2} \, D_u \qquad (3\text{-}80)$$

respectively, where:

f = fraction of the unit's targets undetected

W_u = width of unit

D_u = depth of unit

E_w, E_d = maximum expected error in location parallel to unit boundaries.

An actual location is simulated by randomly selecting a location within the error boundaries as illustrated in Figure 3-15. The collection system's errors are then simulated by adding the respective simulated errors to this location to obtain X_{est}, Y_{est}, the reported estimated location of the target unit.

(g) Scheduling Receipt of Sensing Report. So far within COLLECT, current time is that time at which vulnerability to collection was expected to start, according to CCOLLM. In the case of radar, the active radar beam has presumably begun to sweep over the moving unit; and, in the case of an UGS field, the moving unit has presumably entered the field. If detection is to occur at all in this trial, it should occur at this point or very shortly after. From detection to issuance of a sensing report, however, time is consumed in tracking the target, obtaining information, preparing the report, and getting the report transmitted to the first intelligence analysis center with which a direct communication link is maintained. This delay time is a function largely of the type of sensor involved; therefore, an average delay, input for this sensor, is added to current time for the scheduled time the sensing report will be received at its first intelligence analysis center.

(h) Targets for Fire Missions. A copy of the sensing report is also sent directly to the simulated target intelligence section of the cognizant fire support organization. To simulate some of the steps involved in this separate channel, COLLECT performs several special functions. First, a portion of the Creative Processing Submodel is used to estimate the type and size of unit acquired, based on the type and number of items in the sensing report. Second, a special time delay is randomly chosen from a uniform distribution between 5 and 10 minutes. This delay is intended to simulate that of target intelligence processing to develop a fire mission. Third, a special routing code (INCOPR = 12) is assigned, and receipt at the fire support coordinate center as a potential fire mission is scheduled according to the random delay obtained. The Decision Submodel will then determine whether fire support will actually be requested.

(3) Acquisition of Artillery Fire (CCOLLF). The logic of CCOLLF simulates the capability of countermortar/counterbattery radars (CMR/CBR) to detect and locate firing artillery and mortar fire units. When a radar site detects and locates a fire unit it will generate a sensing report for processing within the Intelligence and Control Model. The following discussion describes the logic used within the submodel to represent the performance of either the dual beam intercept type radar (e.g., MN/MPQ-4A) or the continuous tracking type radar (e.g., MN/MPQ-10A) (References 26, 27).

(a) Dynamic Site Control Data. Each radar site simulated in the model must be initially located prior to initiation of the game. These locations can be changed between successive game periods by gamer control and are also subject to automatic repositioning during the game play as discussed later in the MOVSEN routine. To maintain orientation control of the radar sites the gamer also is required to define a sector of responsibility for each individual site.

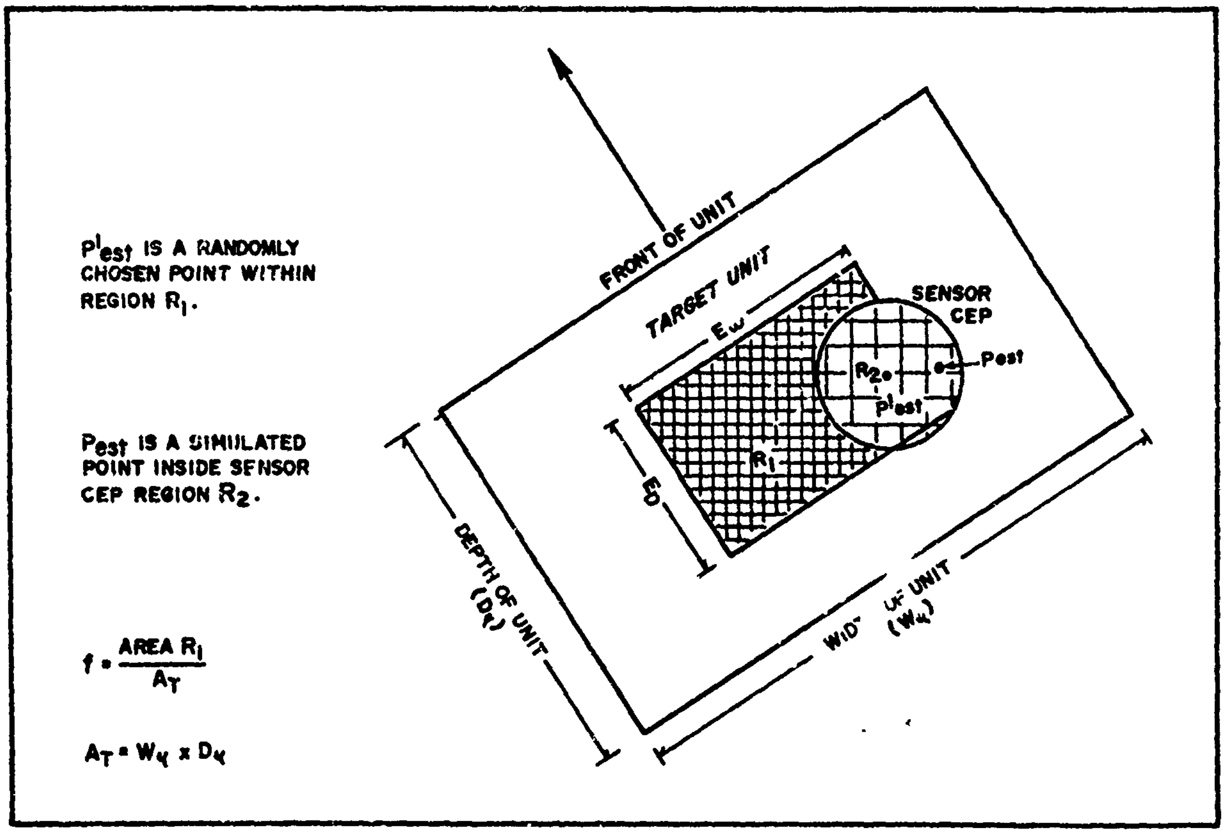

Figure 3-15. Unit Location Error for MTI Ground-Based Radar

(b) Event Sequencing of the Submodel:

1. Fire Mission Volley. Following the firing of each volley of every fire mission fired in the Area Fire/TACFIRE Model of the DIVWAG system, the routine CCOLLF is entered. Each radar site simulated in the model is checked for a potential detection capability against the fire unit firing the volley. A macroflow of the routine is illustrated in Figure 3-16.

2. Site Operational Status. Every site maintains an operational status record of its activity to allow a proper interface with the event sequencing of calls to CCOLLF described above. Thus, each site maintains a record of the following data to allow it to interact realistically with the fire missions fired during the game period:

- Identification of the fire mission currently being tracked, if any
- Number of rounds tracked in this fire mission
- Time at which radar site will be available to track another fire mission, if currently tracking
- Identification of the fire mission last reported.

This site operability status is needed to determine properly the current status of each radar site when the routine is entered at some time reflecting the firing of a volley by enemy artillery or mortar fire units.

(c) Trajectory Detection Geometry. Figure 3-17 illustrates the geometry involved in the interaction of a radar site, fire unit, and projectile path to a target. The radar site is at P_R, the fire unit at P_{fu}, and the target at P_T.

1. Site Mask Angle. The mask angle of the radar site, ϕ_M, is used to compute the points P_1' and P_2' in the trajectory of a round. P_1' is the point at which the projectile becomes detectable above the mask, and P_2' is the point at which it disappears below the mask. The portion of the trajectory from P_1' to P_2' is vulnerable to detection if the range of the radar is great enough.

2. Trajectory Above Mask. The points P_1', P_2' are determined in the following steps. Step 1: Compute h_F, the mask elevation at the fire unit, and h_T, the mask elevation at the target as:

$$h_F \cong R_{RF} \sin\phi_M \qquad (3\text{-}81)$$

$$h_T \simeq R_{RT} \sin\phi_M \qquad (3\text{-}82)$$

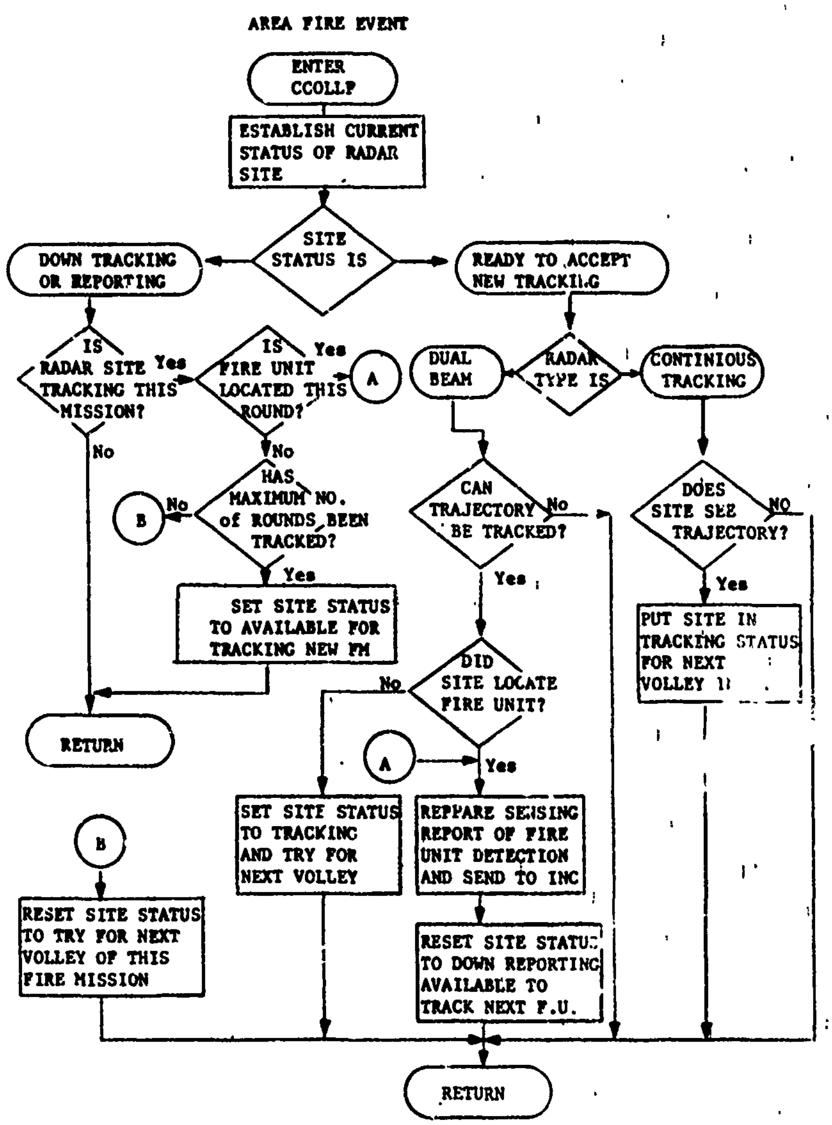

Figure 3-16. Macroflow of CCOLLF

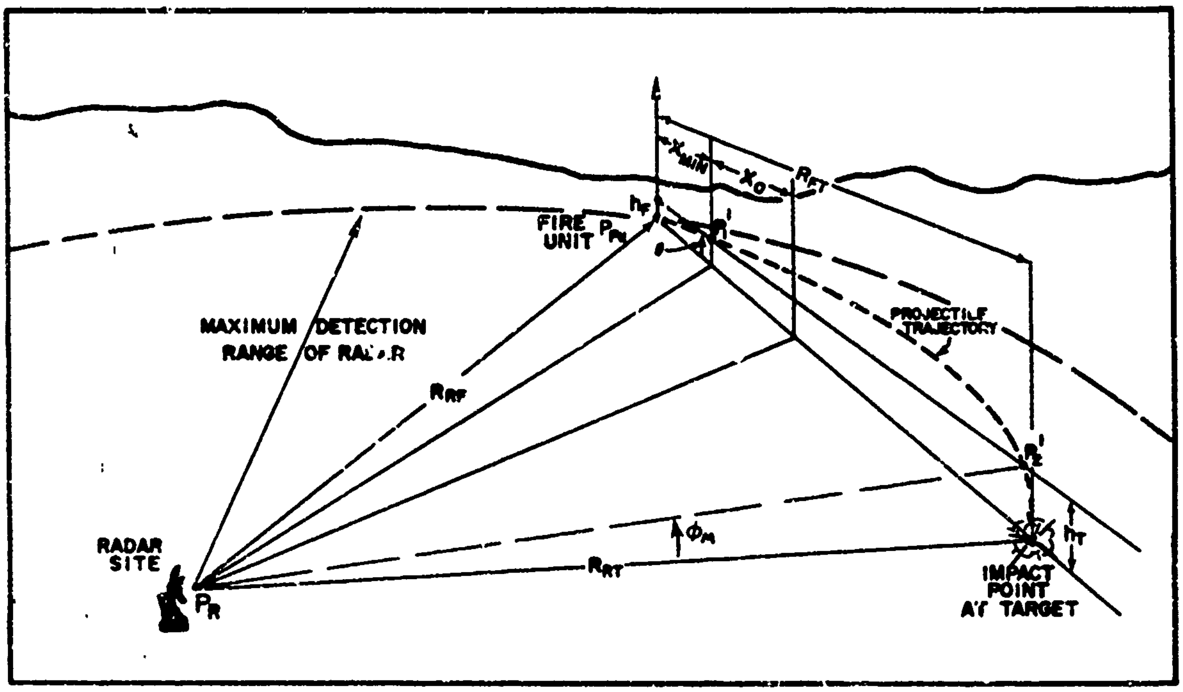

Figure 3-17. Geometry of Countermortar/Counterbattery Artillery Fire Acquisition

where:

R_{RF} = horizontal radar site range to fire unit

R_{RT} = horizontal radar site range to target

Step 2: In the plane of the projectile trace (Refer to Figure 3-17) construct a straight line intersecting points h_F and h_T as:

$$y - h_F = \left(\frac{h_T - h_F}{R_{FT}}\right) x \tag{3-83}$$

Step 3: Construct the equation of the projectile in the coordinate system as:

$$(x - \frac{R}{2})^2 = - \frac{R^2}{4h_p} (y - h_p) \tag{3-84}$$

where R is equal to R_{FT} and h_p is the maximum trajectory height. This height is determined as follows by using the equations pertinent to the projectile trajectory:

$$R = (V_p \cos\Theta) t \tag{3-85}$$

$$h_p = \frac{1}{8} g t^2 \tag{3-86}$$

and:

$$gt = 2V_p \sin\Theta \tag{3-87}$$

where:

g = acceleration of gravity (9.8 meters per second^2)

V_p = muzzle velocity of projectile

Θ = angle of fire (elevation)

t = time for projectile to reach peak height, h_p

Combining equations 3-85 and 3-87 to eliminate t results in:

$$V_p^2 = \frac{Rg}{2 \sin\Theta \cos\Theta} \tag{3-88}$$

Then solving Equations 3-85 and 3-86 to eliminate t and substituting V_p^2 from Equation 3-88 results in the following equation:

$$h_p = \frac{R \cdot \tan\Theta}{4} \tag{3-89}$$

When the quantity h_F is inserted into Equation 3-84, the following is obtained for the trajectory of the projectile:

$$x^2 - Rx + \frac{R}{\tan\Theta} y = 0 \qquad (3\text{-}90)$$

Step 4: Solve for intersection points. If Equation 3-83 is solved for y and this value is inserted into Equation 3-90, the resulting quadratic in x is given by:

$$x^2 + \left(\frac{h_T - h_F}{\tan\Theta} - R\right) x + \frac{R}{\tan\Theta} h_F = 0 \qquad (3\text{-}91)$$

or:

$$x^2 + Bx + C = 0 \qquad (3\text{-}92)$$

Thus, the solutions for x are given by:

$$x^{\pm} = \frac{-B \pm [B^2 - 4C]^{1/2}}{2} \qquad (3\text{-}93)$$

if the quantity in brackets is greater than zero. If such is not the case then no detection is possible since the projectile's path is below the mask of the radar. Finally, letting:

$$xmin = \min(x^+, x^-) \qquad (3\text{-}94)$$

and:

$$xmax = \max(x^+, x^-) \qquad (3\text{-}95)$$

the coordinates of P_1' and P_2' are expressed as:

$$P_1' \quad x_1' = x_{fu} + \left(\frac{xmin}{R_{ft}}\right)(x_{tgt} - x_{fu}) \qquad (3\text{-}96)$$

$$y_1' = y_{fu} + \left(\frac{xmin}{R_{ft}}\right)(y_{tgt} - x_{fu}) \qquad (3\text{-}97)$$

$$x_2' = x_{fu} + \left(\frac{x_{max}}{R_{ft}}\right)(x_{tgt} - x_{fu}) \quad (3\text{-}98)$$

P_2'

$$y_2' = y_{fu} + \left(\frac{x_{max}}{R_{ft}}\right)(y_{tgt} - y_{fu}) \quad (3\text{-}99)$$

3. Trajectory in Range. Using the portion of the trajectory above the mask, the portion of the trajectory actually vulnerable to detection is determined from the range capability of the radar site against this type of round and from the current scan sector of the radar site.

4. Fraction of Ascending Trajectory in Range. After applying the sector and range geometry described above, the portion of the ascending trajectory that is vulnerable to detection is computed. This fraction is used in estimating the accuracy to which a firing location can be determined

(d) Detection Logic:

1. Continuous Tracking Type Radar. When an incoming round passes the geometry and range screen discussed above for a continuous tracking radar site, this site is potentially able to detect the round if it is not already down tracking or reporting on another fire mission. If the site is available, a random number is compared to the probability of seeing the round or volley on the display screen to determine if it is detected. If a detection is made the status of the site is switched to tracking and will track the next round of the fire mission. Thus, a minimum of two successive volleys is required for a continuous tracking radar site to locate the fire unit.

a. Detection of a Subsequent Round. When a subsequent round is fired in the fire mission the round is tracked, and an estimate of the location error is made as follows:

$$E_{est} = \frac{1}{3}\frac{CEP}{F_t}\frac{1}{N_r^{1/2}}\left(\frac{R_{ft}}{R_{ft} - 2x_a}\right) \quad (3\text{-}100)$$

where:

N_r = number of rounds tracked in the mission

F_t = total fraction of entire trajectory tracked

X_a = length of ascending trajectory tracked

CEP = expected location accuracy achieved against incoming rounds in 50 percent of instances tracked where tracking conditions are typical (i.e., typical conditions are tracking of approximately two thirds of the total trajectory of which nearly one half of the ascending portion is tracked).

b. Decision on Location Error. The decision as to reporting a location is obtained by comparing the error estimate, E_{est}, with the maximum allowable error, E_{max}, for reporting a location; i.e., all reported locations must have an estimated error E_{est} less than E_{max}, where E_{max} is a constant data input value which allows the gamer to require a certain location accuracy for sending in a counterbattery sensing report.

c. Limiting Down Time. To prevent the site from being out of action and waiting on a pickup point indefinitely, the site is assigned a maximum time to be down on a pickup point and also is limited to tracking a maximum of five rounds for the particular mission involved. Thus, if the fire unit cannot be located accurately enough within five rounds, or if the fire unit quits firing, the radar site will automatically return to an available for tracking status.

2. Dual Beam Type Radar. The response of a dual beam site to an incoming round is similar to the continuous tracking type with two exceptions: (1) the dual beam type radar is capable of locating the fire unit on the initial volley, and (2) the estimated location error is computed as follows:

$$E_{est} = \frac{2}{3}CEP \frac{1}{N_r^{1/2}}\left(\frac{R_{ft}}{R_{ft} - 2x_a}\right) \qquad (3\text{-}101)$$

The CEP for a dual beam is the expected accuracy achieved in 50 percent of the instances tracked in typical conditions where typical conditions are locating the beam intercept points at a position approximately one third of the distance between the firing unit and apogee of the round.

(e) Estimate of Number of Tubes or Missiles. The estimate of the number of tubes or missiles in the volley is given as:

$$N_{TM} = N_R^F \qquad (3\text{-}102)$$

where N_R^F is the actual number fired.

(f) Fire Unit Location Estimate. The location of the fire unit is estimated from the error estimate, E_{est}, as follows:

$$x_{est} = x_{act} + \text{ENORM}\ (\sigma_{E_{est}})\ \cos(\Phi_r) \qquad (3\text{-}103)$$

$$y_{est} = y_{act} + \text{ENORM}\ (\sigma_{E_{est}})\ \sin(\Phi_r) \qquad (3\text{-}104)$$

where $\sigma_{E_{est}}$ is related to E_{est} as:

$$\sigma_{E_{est}} = \frac{E_{est}}{(2\ln 2)^{1/2}} \qquad (3\text{-}105)$$

and Φ_r is a random angle between zero and 2π.

(g) Reporting. Once the fire unit has been detected by a radar site, a sensing report is prepared and sent to the Intelligence and Control Model fire support and intelligence channels with delay times representing tracking time, report preparation time, and transmittal time delays.

(4) Movement of Ground-Based Sensors (MOVSEN). The employment and position requirements for a sensor site depend on the tactical mission and the physical characteristics of the sensor. As battlefield dynamics change, such as withdrawal of friendly forces or penetration of enemy forces, the requirement to move a ground-based sensor may develop. To simulate the activities of the process of sensor site selection and movement of the sensor within the DIVWAG Model, the following model concept was developed.

(a) The criteria for the movement of the sensors is based on the movement of the FEBA during game period dynamics. For each ground-based radar there is a maxiuum and minimum range from the FEBA when the associated force is in an offensive posture and a set of ranges for the defensive posture loaded as input. Determining the force's posture by way of FEBA movement, the appropriate range brackets are chosen, and if FEBA movement causes the sensor location to fall outside this maximum-minimum range bracket, a requirement exists to move this sensor to a new site.

(b) Knowing the slope of the battlefield, the direction of the FEBA movement, and the range limits of this specific sensor, the new sensor site location is defined such that movement of the sensor is in the direction of the FEBA movement and to the range limit furthest from the current sensor location. The model considers delay times to power down the sensor site, to move to the new site location, which is a function of the vehicular speed of the prime mover of the sensor, and to power up once at the new site. During these periods of delay, this sensor will not be available for detection. The orientation of the sensor remains unchanged after movement to the new site. The orientation can be changed by the gamer between periods through the Operating Instructions of the Orders Input Processor.

5. CREATIVE PROCESSING SUBMODEL:

a. General:

(1) Purpose and Scope. The purpose of the Creative Processing Submodel is to simulate the intelligence analysis and related processes. This submodel is primarily concerned with piecing together individual sensing reports as they are collected to develop increasingly complete information about the opposing units and increasingly general intelligence about the opposing force (References 3, 4, 10, 14, 15, 17-20). The Creative Processing Submodel is used each time a sensing report is received at the simulated intelligence analysis center of any unit at any of the three echelons represented (battalion, brigade/regiment, and division). Receipt of a sensing report may be from a sensor (unprocessed report) or from another intelligence analysis center (processed report). Any modification of a sensing report during analysis at any analysis center may be cause for recirculation of the modified report to other centers. The general military functions simulated by the Creative Processing Submodel include preliminary screening and classification of the sensing report, analysis of the report in comparison with the contents of the local intelligence file of the specific intelligence analysis center, and maintenance of that file. This analysis develops information and yields inferences about the opposing unit which the sensing report is believed to reflect. In addition, the Creative Processing Submodel determines the time delay for each processing of a report and for each decision-making sequence. Message volume, capacity, and queuing, however, are not considered in this determination. The output sensing report from a pass through the Creative Processing Submodel is sent to the Decision Submodel for decisions on further routing. The contents of the division level intelligence files (one Blue and three Red) serve as the basis for the periodic Division Intelligence Summary.

(2) Description of Submodel. For purposes of this chapter, the description of the Creative Processing Submodel will be organized under:

- determination of time required for processing
- deduction of type and size of target sensed
- comparison of incoming report with intelligence file, and tests for redundancy
- consolidation, upgrading, and updating of intelligence
- filing and discarding intelligence records
- special bookkeeping operations
- determination of time required for decision-making.

b. Determination of Time Required for Processing. The first step performed by the Creative Processing Submodel when it receives a sensing report is to determine the average time delay for the processing of the report at the echelon of receipt. Delay times are required for the echelon and type units which will conduct the processing as part of the game data base. (See Volume VI, DIVWAG Data Requirements Definition). Using the appropriate delay time, an event which will represent the completion of creative processing functions is scheduled.

c. Deduction of Type and Size of Target Sensed. After a preliminary screening step that determines whether the target sensed is within the area of responsibility of the friendly unit now analyzing the report, an estimate is made of the type and size of target sensed. Subroutine UTSR (the Update Type and Size Routine) makes the type and size deduction, based on the data in the nine target content categories in the sensing report (personnel, tanks, APCs and APC-like vehicles, artillery tubes, artillery missiles, air defense guns, air defense missiles, aircraft, and vehicles not otherwise classified).

(1) Type Deduction. The presence or absence of identified items in the various categories is the key used for type deduction. The logic steps in type deduction are as follows:

(a) If aircraft were identified, the unit is inferred to be an air unit.

(b) If no aircraft were identified, but tanks and APCs were identified, and if the smaller number constitutes at least 20 percent of the sum of tanks and APCs, then the unit is inferred to be a mixed reinforced force of armor and mechanized infantry, regardless of the number of other items identified.

(c) If the 20 percent criterion is not met, and if the number of APCs exceeds the number of tanks, the unit is inferred to be mechanized infantry. If the tanks exceed APCs, however, the unit is inferred to be armor.

(d) If no aircraft and no APCs were identified, but tanks were identified, the unit is inferred to be armor, regardless of what was identified in other categories.

(e) If no aircraft and no tanks were identified, but APCs were identified, the unit is inferred to be mechanized infantry, regardless of what other items were identified.

(f) If no aircraft, tanks, or APCs were identified, but artillery tubes were identified, the unit is inferred to be tube artillery, regardless of other items identified.

(g) If no aircraft, tanks, APCs, or artillery tubes were identified, but artillery missiles were identified, the unit is deemed to be an artillery missile unit, regardless of other items identified.

(h) If no aircraft, tanks, APCs, artillery tubes, or artillery missiles were identified, but air defense guns were identified, the unit is deemed to be an air defense unit.

(i) If no aircraft, tanks, APCs, artillery tubes, artillery missiles, or air defense guns were identified, but air defense missiles were identified, the unit is considered to be an air defense missile unit.

(j) If no aircraft, tanks, APCs, artillery tubes, artillery missiles, air defense guns, or air defense missiles were identified, but engineer vehicles were identified, the unit is typed as an engineer unit.

(k) If no equipment items were identified, but dismounted personnel were identified, the unit is considered to be infantry.

(l) If no items in any of the nine categories are identified, the unit is designated as unknown type.

(2) Size Deduction. Deduction of size depends upon the type of unit inferred above except that a unit of unknown type is always deduced to be a company. The number of items identified in that target content category corresponding primarily to the deduced type is used to infer size of unit. For instance, if the unit was estimated to be infantry type, the number of dismounted personnel identified is used for the size inference. For a mixed armor and mechanized infantry unit, however, the number of tanks is used, then the number of APCs is used, and the size estimates compared. Size is expressed in terms of echelon, with seven possible size categories, from platoon through brigade/regiment, and with an intermediate category between each normal echelon designation. The estimated size of the target unit is obtained by use of an input table containing an upper and lower item number limit for each of the seven size categories and each of the ten (excluding unknown) type categories. If the number of items identified in that target content category corresponding primarily to the deduced type falls within the limits of a size category, then that category is taken as the estimated size of the unit, except for the mixed armor and mechanized force. For the mixed armor and mechanized unit, if both the tank and APC estimates are the same size, the unit size is judged to be two categories larger than the estimate. If one estimate is one category larger than the other estimate, the unit size is judged to be one category larger than the larger of the two individual estimates. If one size estimate is two or more categories larger than the other estimate, the larger estimate is assigned to the unit. Estimated size is limited to a maximum of brigade/regiment.

d. Comparison of Report with Intelligence File and Tests for Redundancy. After the type and size of unit reflected by the sensing report has been deduced, the incoming sensing report is compared with records already in the local intelligence file, and tests are made to determine whether this report reflects a new enemy unit or merely another report on a unit about which information was filed earlier. Each report record in the local file of the unit

performing the analysis is compared with the incoming report. Each comparison involves the redundancy tests described below.

(1) Type Test. If the type of unit in the incoming report is not the same as the type of unit in the report on file being compared, the incoming report is deemed not to be redundant, with one exception. Three types--armor, mechanized infantry, and reinforced task force--are considered synonymous for purposes of the type test. If the incoming report is not judged redundant, the next file record is compared, until all file records have been considered. If the unit in the incoming report is found to be the same type as a file record, then the location test is performed.

(2) Location Test. If the unit reflected in the incoming report appears to be located more than some threshold distance from the unit reflected in the report on file being compared, there is a strong probability that the two units are not the same, provided that adequate consideration is given to the possible movement of the unit between the acquisiton times of the two reports. To make such a test, the model uses the report on file data for the base point. If the unit in the file record was reported to be moving, the direction and rate of move in that record is used to project the probable location of that moving unit at the time the incoming report data were originally acquired by the sensor. No time limit is imposed on the difference between acquisition times for this test. The threshold distance for the location test is obtained from an input table of "unit radii," according to the type and size estimate of probable parent unit. The unit in the file record is deemed the probable parent if its estimated size at least equals that of the incoming report. If the incoming report unit now meets the location test, it is inferred that the two units are the same. If the location test is not met, the incoming report unit is inferred not to be the same. (If the latter is inferred for all file records compared, the incoming report is in most cases added to the file as a new record.)

e. Consolidation and Updating of Intelligence. Whenever a record in the intelligence file is deemed, on comparison with an incoming report, to represent the same opposing unit, the content of the incoming report and the file record are consolidated. The consolidated and updated information replaces that in the file record and also that in the incoming report. Thus, the incoming report now is transformed into a revised report, which continues through the comparison process at this intelligence analysis center and may be further modified if another file record is deemed to represent the same opposing unit. In the latter case, file records will also be consolidated. The way in which this consolidation and upgrading process is performed depends upon the circumstances and data contained in the compared reports. The principal items in a file record are listed in Figure 3-18.

(1) Age of Report. In consolidating the information from two reports, the model uses the more recently sensed data for many of the data items in the report. The more recently sensed values are adopted for sensing time, estimated activity of the target, and its estimated direction and rate of movement, if any.

Time of sensing (in days, hours, and minutes of game time)

Estimated location of target (x-y coordinates in meters)

Estimated activity of target (11 types of activity)

Estimated direction of move, if moving

Estimated rate of move, if moving (meters per minute)

Estimated size of unit (7 size categories - platoon through brigade/regiment)

Estimated type of unit (11 type categories)

Estimated number of personnel "collected"

Estimated number of tanks "collected"

Estimated number of APCs and APC-like vehicles "collected"

Estimated number of artillery tubes "collected"

Estimated number of artillery missiles "collected"

Estimated number of air defense guns "collected"

Estimated number of missiles "collected"

Estimated number of aircraft "collected"

Estimated number of vehicles not otherwise classified "collected"

Sensing report number (unique number, assigned by sensor)

Priority of report to unit last processing report (1 = within processor's area of responsibility; 2 = outside)

Number of times this unit has been acquired.

(A number of additional items are contained for bookkeeping purposes, for a total of 24 items.)

Figure 3-18. Principal Items in a File Record

(2) Size of Unit. The model gives extra weight to the target location in the report with the larger estimated unit size. In consolidating the location data in two reports, the model picks an intermediate point one third of the separation distance from the superior unit, after projecting the unit location of the file record in the manner described in Paragraph 5d(1) above. If both report units are of the same estimated size, however, the intermediate point picked is one half of the same-time-projected separation distance.

(3) Quantity of Items Identified. In consolidating two reports, the value adopted for quantity of items identified in each of the nine target content categories is always the maximum of the two report values. The maximum is also taken for the number of times the unit was acquired.

(4) Resulting File. As soon as the consolidation is completed, the local priority of the target (defined in Paragraph 5f(1)) is recalculated, based on the area of responsibility of the unit doing the analysis; and the type and size of target is again deduced, as described in Paragraph 5c, above. Thus, the size of units in the intelligence file will tend to increase as the battle progresses. Parent units will tend to emerge as subordinate units are consolidated; therefore, the intelligence files per se in the model cannot supply a detailed history of acquisition events. Rather, the intelligence files, at any point in time, represent the highest level of generalization reached to date from the details fed in.

f. Filing and Discarding Intelligence Records:

(1) Incoming Report Not Redundant. When an incoming sensing report is deemed not to represent the same unit represented by any record already in the intelligence file, the incoming report is added as a new entry in the file, provided that there is space in the file. Battalion files are limited to 10 records, brigade/regiment files are limited to 20 records, and division files are limited to 100 records. If the file is full, an old record, or possibly the incoming record, will have to be discarded. To select the report to be discarded, both the local priority and the latest sensing time of each report are considered. The local priority of each report is either 1 (signifying that the unit represented is within the analyzing unit's area of responsibility) or 2 (signifying the unit is outside the area of responsibility). If the incoming report has local priority 1, and if there are any priority 2 records in the file, the oldest (longest time to last sensing) priority 2 record is discarded. If the incoming report has priority 2 and all file records have priority 1, the incoming report will be discarded. If all reports are the same priority, the oldest report will be discarded.

(2) Incoming Report is Redundant. When an incoming sensing report is deemed to represent the same unit as a record in the intelligence file, the consolidation process described above, Paragraph 5e, generates one consolidated record.

(a) Redundant with One File Record. If only one record in the file is deemed to represent the same unit, this file record retains its report number, but the other contents of the record are replaced by the new consolidated record. A copy of the consolidated record bearing the report number of the incoming report is sent to the Decision Submodel to determine if it should be routed to other intelligence analysis centers.

(b) Redundant with Two File Records. If the incoming report is deemed redundant with two file records, the consolidation process occurs twice: and the results of the first consolidation are carried along by the revised incoming report and integrated into the second consolidation. Since the first redundant file record was essentially replaced by the first consolidated record, the resulting first redundant file record does not reflect the second consolidation; therefore, the resulting first redundant file record is completely expunged and replaced by the topmost record in the file, and the space formerly occupied by the latter is made available for later additions to the file. The second redundant file record is retained (maintaining the report number of the first report to reach the file but containing the results of both consolidations). A copy of the final consolidated record bearing the report number of the incoming report is sent to the Decision Submodel.

(c) Redundant with More than Two File Records. If the incoming report is deemed redundant with more than two file records, the procedure outlined in the immediately preceding paragraph is extended. All redundant file records except the last are expunged and the end of file records are shuffled into those spaces, leaving spaces at the end of the file. The last file record deemed redundant becomes possessor of the highest level of information or inferences reached, including that of the incoming report, but not the latter report number. Thus, for use in the end-of-period Division Intelligence Summary, for gamer use, maximum possible continuity in report number ("ID Number" in the summary report) is maintained to facilitate comprehension of the contents of successive summary reports. This continuity is needed, since no other unit naming scheme is in effect.

g. Special Bookkeeping Operations. A number of special operations are performed by the model in order to keep track of the records contained in the intelligence files and to show what report was sent to what unit. The latter provision allows the Decision Submodel to avoid duplicate transmission of a report to n intelligence center that has already received the identical report. These provisions are to facilitate internal operation of the Intelligence and Control Model and will not be described further here.

h. Determination of Time Required for Decision-Making. The last function performed by the Creative Processing Submodel is determination of the time required for decisions on whether other intelligence analysis centers should receive the sensing report after its processing at this center. This time delay is used to schedule the completion of the decisions. The same procedure is used for this delay time as used for processing delay, described in Paragraph 5b above, except that another input table of average delay times is used. No

capacity, volume, or queuing is considered by the model. They must be included in the input times.

6. DECISION SUBMODEL:

a. General:

(1) Purpose and Scope. The purpose of the Decision Submodel is to simulate certain decisions concerning the routing, use, or application of the intelligence collected and processed. The decision functions specifically simulated by this model are:

(a) Intelligence Message Routing. The decisions simulated involve which units' intelligence analysis centers should receive a given processed sensing report. Also simulated is the delay before the message will be received by each designated recipient.

(b) Fire Support Coordination. The decisions simulated in this area concern whether an incoming target intelligence report qualifies for a request for fire support. If the target qualifies, the type of fire support to be requested is selected; and if the type of support first selected is unavailable, alternate resources are selected.

(2) Description of Submodel. The Decision Submodel description is concerned with two areas, information/intelligence flow and fire support coordination.

b. Information/Intelligence Flow. The information or intelligence flow decisions made by the Decision Submodel reflect an assumed information flow structure. This structure, applied to both the Blue and Red forces, represents a generalized type of communication network. This structure accommodates a single division force. The model uses a set of communication criteria (an input matrix) to decide which unit at which echelon qualifies to receive a particular report, as a function of report content. Actual routing decisions follow, depending upon whether a qualifying recipient has already received the identical report. Appropriate delays are inserted from input tables (References 17, 19, 21).

(1) Information Flow Structure. The information flow structure built into the model contains three sender echelons: battalion, brigade/regiment, and division. The number of units at each echelon of a force is part of the game TOE input. A division artillery unit is accorded by the model to each division and is also accessible to direct communication from the subordinate brigades/regiments. The specific flow possibilities are defined below.

(a) Battalion. A battalion may send a sensing report directly to the following recipients:

1. Parent division headquarters

2. Parent brigade headquarters

3. Adjacent on-line battalions.

(b) Brigade/Regiment. A brigade or regiment may send a sensing report directly to the following recipients:

1. Parent division headquarters

2. Adjacent on-line brigade/regiment headquarters

3. Subordinate battalions.

(c) Division. A division may send a sensing report directly to subordinate brigades/regiments.

(d) Sensor. Flow from the sensor to the first intelligence analysis center is determined by input data and does not depend on choices made by the Decision Submodel.

(2) Threshold Matrix:

(a) Concept. Each sender echelon--battalion, brigade/regiment, and division--has its own threshold matrix, which shows the principal criteria that must be met by any sensing report for it to qualify for sending to each of the possible recipients of that sender. To qualify, for a given recipient, a sensing report must contain values which meet (=) or meet or exceed (≥) at least one of the matrix values, which are input in the following target data categories:

1. Estimated size ≥

2. Estimated type =

3. Estimated activity =

4. Estimated number of personnel ≥

5. Estimated number of tanks ≥

6. Estimated number of APCs ≥

7. Estimated number of artillery tubes ≥

8. Estimated number of ADA weapons ≥

(b) Example of Threshold Matrix. Figures 3-19, 3-20, and 3-21 are examples of the threshold matrix for battalion, brigade/regiment, and division senders, respectively. If a cell in the matrix is left blank, no test is performed on that cell.

(3) Other Criteria. In addition to the principal criteria in the input threshold matrix, several rules are incorporated in the logic of the Decision Submodel, which also limit where a specific report may be sent, within the possibilities of the general flow structure. These rules, mainly intended to prevent excessive flows within the model, are described below.

(a) A maneuver battalion will not send a recirculated report (one that has not come directly from the sender battalion's sensor) to the adjacent on-line battalions.

(b) Recirculated reports whose age from last time of sensing is greater than certain limiting values will not be received by the respective echelon. Limiting values currently used are 1 hour for battalion level, 2 hours for brigade/regiment level, and 3 hours for division level.

(c) The identical report (no change in content) will not be sent twice to any unit.

(d) No reports that have been processed through the general (nontarget) intelligence channel are sent into the target intelligence channel to be considered for fire support.

c. Fire Support Coordination. The necessary simulation of decision-making in the fire support coordination area requires target intelligence that may be different from some of the intelligence emanating from general intelligence analysis centers; therefore, a separate target intelligence channel is provided in the model to convey target intelligence from the sensor through limited processing steps directly to the point where a decision is made concerning eligibility of the sensing report for fire support. If fire support is justified, a choice of type of fire support (attack helicopter, TACAIR, ground-based artillery) is made and a request is sent to the appropriate submodel. If resources are unavailable or weather prevents utilization of the first type of fire support chosen, that information is returned to the Decision Submodel. Then, a second choice is made. If the second choice is also returned, the request goes automatically to ground-based artillery, if that type had not already been chosen. Other details of the fire mission are handled by the respective fire models, based on the information in the sensing report sent (References 22-24).

(1) Target Intelligence Channel. The target intelligence channel starts at the sensor, or sensor monitor. A duplicate copy of the sensing report entered in the general intelligence channel is provided specifically for target intelligence purposes. (See Paragraphs 1c, 4c(8), and 4d(7) above.)

Receiving Echelons	Estimated Size	Estimated Type	Estimated Activity	Estimated Number of Personnel	Estimated Number of Tanks	Estimated Number of APCs	Estimated Number of Arty Tubes	Estimated Number of ADA Weapons
Division	B_n^+	--	-	--	23	21	10	[illegible]
Brigade	Co	Armor	--	--	5	4	5	[illegible]
DS Arty	Plat	--	--	--	3	2	3	2
Adjacent Battalions	Co	Armor	--	--	5	4	5	2

Figure 3-19. Threshold Matrix for Battalion to Pass Information or Intelligence to Other Echelons

Receiving Echelons	Estimated Size	Estimated Type	Estimated Activity	Estimated Number of Personnel	Estimated Number of Tanks	Estimated Number of APCs	Estimated Number of Arty Tubes	Estimated Number of ADA Weapons
Division	B_n	--	--	--	21	19	10	6
Adjacent Brigades	B_n	Armor	--	--	21	19	10	6
Subordinate Battalions	Co	Armor	--	--	5	4	5	2
DS Arty	Plat	--	--	--	3	2	3	2
DIVARTY	Plat	--	--	--	3	2	3	2

Figure 3-20. Threshold Matrix for Brigade to Pass Information or Intelligence to Other Echelons

Receiving Echelons	Estimated Size	Estimated Type	Estimated Activity	Estimated Number of Personnel	Estimated Number of Tanks	Estimated Number of APCs	Estimated Number of Arty Tubes	Estimated Number of ADA Weapons
Subordinate Brigades	Co	--	--	--	7	6	5	2
DIVARTY	Co	--	--	--	7	6	5	2

Figure 3-21. Threshold Matrix for Division to Pass Information or Intelligence to other Echelons

After the simulation of rudimentary target intelligence processing, and a relatively short delay, the sensing report reaches the Decision Submodel.

(2) Qualification for Fire Support. The decision as to whether the acquired target qualifies for fire support is made with the use of a decision table. This table is also used for choice of type of fire support. A part of this decision table is input data (limits of range beyond FEBA for use of attack helicopters and ground-based artillery), while the rest of the table is incorporated in the structure of the Decision Submodel. The fire support decision table provides for 22 different situations, for each of which a predetermined decision is supplied. The 22 different situations involve different combinations of states or criteria for eight factors concerning estimated location and nature of target, visibility, and availability of aerial fire support resources.

(a) Factors Considered. The eight factors considered in the decision table and the various categories or states attributed to each factor are described below in the order considered.

1. Range from FEBA to Target. The estimated location of the target is translated by the model into a perpendicular distance beyond the current FEBA trace, which is established as described in Chapter 2. This perpendicular distance is then placed in one of four nonexclusive categories, based on the input range limit for employment of attack helicopters and the input range limit for employment of ground-based artillery. These four categories of range from FEBA to target are as follows:

a. Within range limit for attack helicopters.

b. Within range limit for ground-based artillery.

c. Beyond range limit for ground-based artillery.

d. Range irrelevant. Range is ignored in one of the situations considered.

2. Target Type. The type of target, as inferred by the Creative Processing Submodel, is the second factor considered in the decision table. Nine different type categories are comprehended within the decision table, as follows:

a. Armor.

b. Mechanized infantry.

c. Infantry.

d. Tube artillery.

e. Missile artillery.

f. Air defense.

g. Reinforced task force. If a target is so designated, the decision table considers it to fit in both the armor and mechanized infantry categories.

h. Type irrelevant. Type is of no consequence in two of the 22 situations provided for in the decision table and is thus ignored.

i. High priority target. This category is provided for high-threat targets such as those with nuclear delivery capability. As presently constructed, the model places only targets inferred to be missile artillery type in this category.

3. Target Size. The inferred size of target is the third factor considered in the decision table. Four nonexclusive categories are distinguished, as follows:

a. Platoon or larger.

b. Company or larger.

c. Battalion or larger.

d. Size irrelevant. Size is ignored in eight of the 22 situations provided for in the decision table.

4. Target Activity. Target activity is considered fourth by the decision table. Three nonexclusive categories are defined, as follows:

a. Attacking or moving. Attacking is applicable only to maneuver battalions. Moving is applicable to any unit.

b. Attacking.

c. Activity irrelevant. Target activity is ignored in 19 of the 22 situations in the decision table.

5. Blue or Red Force. The fifth factor considered in the decision table is whether the target belongs to the Blue or to the Red force. Three of the 22 situations use this factor, while the others ignore it.

6. Visibility. Visibility, the sixth factor, is considered in 14 of the 22 situations. Two categories are distinguished, as follows:

a. Good visibility. The information pertaining to whether this criterion is met is determined by the Air Ground Engagement Model.

b. Visibility irrelevant.

7. Attack Helicopter Availability. The seventh factor considered is attack helicopter availability. Three categories are distinguished, as follows:

a. Attack helicopters available. Availability is determined by the Air Ground Engagement model.

b. Attack helicopters not available.

c. Attack helicopter availability irrelevant.

8. TACAIR Availability. The last factor considered is the availability of TACAIR. Three categories are distinguished, similar to those for attack helicopters, as follows:

a. TACAIR available. Availability is determined by the Air Ground Engagement Model.

b. TACAIR not available.

c. TACAIR availability irrelevant.

(b) Possible Decisions. The structure of the fire support decision table permits four possible mutually exclusive decisions to be reached, depending upon the factors considered. The four possible decisions are:

1. Target does not qualify for fire support. This target (sensing report) is dropped from further consideration within the target intelligence channel.

2. Request attack helicopter fire support.

3. Request ground-based artillery fire support.

4. Request TACAIR fire support.

(c) Decision Process. To reach a fire support decision, the Decision Submodel compares the target information contained in the sensing report with the factor criteria defining one of the 22 situations. If all the criteria are met for that situation, then the decision reached is the one associated with that situation. The Decision Submodel starts with situation 1 and proceeds to consider the situations in order until a situation is found whose complete set of criteria is met by the information contained in the sensing report. The structure guiding this decision process can be described in terms of a decision table.

1. Fire Support Decision Table. Figure 3-22 summarizes the structure involved in this decision process. Each line in the figure represents a situation. The decision process for a given sensing report starts at the left end of the top line. The process moves to the right as long as each criterion is met. As soon as any criterion is not met by the information in the sensing report, the process drops to the left end of the next line. As soon as the process reaches the decision columns, the indicated decision is declared. If a target does not meet all the criteria in any of the first 21 situations, situation 22 declares that the target does not qualify for fire support.

2. Example. Assume that a target is inferred to be a battery of Blue tube artillery located within ground-based artillery range with TACAIR unavailable to Red force. If ground-based artillery range exceeds attack helicopter range, this target will meet the range criterion of the first 20 situations. The target will not, however, meet the type criterion of any of the first 16 situations. In the seventeenth situation, the next three factors--type, size, and activity--are met, but the force criterion is not met. In situation 18 the TACAIR criterion is not met. In situation 19, however, all criteria are met, and the model reaches the decision to request ground-based artillery fire support on this target.

(3) Request for Fire Mission. If the acquired target does qualify for a particular type of fire support, a request is sent to the respective fire model (Air Ground Engagement Model for helicopters or TACAIR, TACFIRE Model for ground-based artillery). The first request may be for helicopter fire support, TACAIR, or ground-based artillery. If the first request is for helicopter fire support, and if the Air Ground Engagement Model does not have resources available, or if weather is unsuitable, a rejection message is sent back to the Decision Submodel. The target is then reconsidered for fire support, with the knowledge that helicopters cannot be utilized; and a second request is prepared. The second request may be to TACAIR, or to ground-based artillery, whichever meets the decision criteria. If the second request is for TACAIR, and if resources are unavailable or weather is unsuitable, a rejection message is sent. When both the first and second requests are for aircraft and both are rejected, ground-based artillery automatically receives the request. If the first or second request is for ground-based artillery, no further requests are made. If ground-based artillery receives the request but does not have immediate resources available, the request is retained there in a fire mission backlog. Size and details of mission are in all cases determined by the respective fire model.

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	CRITERIA								DECISION		
							Resource Availability				
Situation No	FEBA-to-Target Range	Target Type	Target Size	Target Activity	Target Force	Visibility	Attack Helicopters	TACAIR	Request Attack Helicopters	Request Ground-based Artillery	Request TACAIR
1	Irrelevant	Missile Arty	Irrelevant	Irrelevant	Irrel	Good	Irrel	Avail	No	No	Yes
2	Within Attack Helicopter Range	Armor	Plt or greater	Irrelevant	Irrel	Good	Avail	Irrel	Yes	No	No
3	"	Armor	Co or greater	Irrelevant	Irrel	Good	Unav	Avail	No	No	Yes
4	"	Armor	Irrelevant	Attack or Move	Irrel	Irrel	Unav	Unav	No	Yes	No
5	"	Mech	Plt or greater	Irrelevant	Irrel	Good	Avail	Irrel	Yes	No	No
6	"	Mech	Co or greater	Irrelevant	Irrel	Good	Unav	Avail	No	No	Yes
7	"	Mech	Irrelevant	Irrelevant	Irrel	Irrel	Unav	Unav	No	Yes	No
8	"	Air Defense	Plt or greater	Irrelevant	Irrel	Good	Avail	Irrel	Yes	No	No
9	"	Air Defense	Co or greater	Irrelevant	Irrel	Good	Unav	Avail	No	No	Yes
10	"	Air Defense	Irrelevant	Irrelevant	Irrel	Irrel	Unav	Unav	No	Yes	No
11	"	Infantry	Plt or greater	Attack	Irrel	Irrel	Irrel	Irrel	Yes	No	No
12	"	Infantry	Bn or greater	Attack	Irrel	Good	Unav	Avail	No	No	Yes
13	Within Ground-Based Artillery Range	Infantry	Irrelevant	Irrelevant	Irrel	Irrel	Unav	Unav	No	Yes	No
14	"	Armor	Co or greater	Irrelevant	Irrel	Good	Unav	Avail	No	No	Yes
15	"	Mech	Co or greater	Irrelevant	Irrel	Good	Unav	Avail	No	No	Yes
16	"	Air Defense	Co or greater	Irrelevant	Irrel	Good	Unav	Avail	No	No	Yes
17	"	Tube Arty	Irrelevant	Irrelevant	Red	Irrel	Irrel	Irrel	No	Yes	No
18	"	Tube Arty	Co or greater	Irrelevant	Blue	Good	Irrel	Avail	No	No	Yes
19	"	Tube Arty	Bn or greater	Irrelevant	Blue	Irrel	Irrel	Unav	No	Yes	No
20	"	Irrelevant	Irrelevant	Irrelevant	Irrel	Irrel	Irrel	Irrel	No	Yes	No
21	Beyond Ground-Based Artillery Range	Irrelevant	Bn or greater	Irrelevant	Irrel	Good	Irrel	Avail	No	No	Yes
22	"	Irrelevant	Irrelevant	Irrelevant	Irrel	Good	Irrel	Unav	No	No	No

Figure 3-22. Fire Support Decision Table

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CHAPTER 4

GROUND COMBAT MODEL

1. MILITARY ACTIVITY REPRESENTED:

a. The Ground Combat Model simulates the interaction between the direct fire weapons of opposing maneuver units engaged in ground combat.

b. Since combat power may be enhanced by employing combined arms forces against the enemy the model permits simulation of the interaction and the effects of weapons of cross-reinforced units. The effectiveness of the maneuver unit is largely dependent on the combinations and coordination of weapon systems within the unit. The distance of separation of weapon systems is limited so that mutual support is possible when weapon density permits.

c. The impact of the environment is represented in the model. All movement in ground combat is subject to the constraints imposed by the environment wherein optimum ability to move forces by ground is degraded by the effects of adverse weather, terrain, and visibility. The application of firepower is largely controlled by the environment since effectiveness of each weapon system is limited by its associated target acquisition capabilities.

(1) Target acquisition cannot occur unless line of sight exists between the observer and target. Line of sight may be severely limited due to terrain roughness, vegetation, and forestation. A firer may lose line of sight on a moving target before firing a round. A moving target may drop out of line of sight during the time of flight of the round.

(2) Target acquisition is limited by visibility, whether due to adverse weather or night combat operations. Under conditions of reduced visibility, target acquisition is enhanced by the employment of night vision equipment.

d. The interaction of each maneuver unit with an opponent is considered by the model in terms of a maneuver unit's effectiveness and vulnerability.

(1) The maneuver unit's effectiveness is influenced by the level of activity. As the level of activity increases, more weapon systems can acquire targets. As individual moving weapon systems stop to fire, the unit movement rate decreases. The possibility of observing an enemy weapon's signature (i.e., evidence of that weapon firing) increases with the level of activity. The chance of hitting such a target is less than against an observed target.

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(2) The maneuver unit's vulnerability is influenced by the level of activity. A firing weapon system may disclose its position and become a target for enemy fire.

e. The Ground Combat Model relies heavily on the existence of data to describe weapon/ammunition effectiveness against varying target types in a combat situation. The model also requires data to describe the target acquisition capabilities of all employed sensor types other than unaided vision.

2. MODEL DESIGN:

a. Model Structure. The Ground Combat Model processes an engagement by examining the interaction between each attacker-defender pair among all surface units in the engagement. The engagement between each pair is represented by modeling the following five areas: unit geometry, target acquisition, firepower potential, firepower effectiveness, and assessment. The Ground Combat Model is modular since there is a separate submodel to perform calculations in each of the five areas. Flow through the Ground Combat Model is depicted in Figure 4-1.

(1) Unit Geometry:

(a) All combat units are represented as being bounded by rectangles of variable width and depth. Each such rectangle is further subdivided into as many as four rectangular bands of equal area. Each band contains a predetermined percentage of the unit's total equipment of each type based upon the unit type and mission. Equipment of each type in each band is distributed uniformly. Participation in an engagement is limited to direct fire weapons and targets in the band nearest the enemy.

(b) Associated with each engaged unit is a specified location, a velocity (possibly zero), and coordinates of its objective location. From these values a vector specifying both the magnitude and direction of velocity can be constructed. The difference vector of the two units' velocity vectors yields the relative velocity of the units, another vector. This vector specifies a unique direction and magnitude on the battlefield. The orientation of each engaged unit pair is determined by requiring the front of each unit to be perpendicular to this direction. The closing speed is the magnitude of the relative velocity. This scheme is depicted in Figure 4-2 for the special case of a stationary defender. In Figure 4-2 the locations of one defender (on the left) with zero velocity and one attacker with velocity directed along the broken line are shown for successive engagement iterations (from top to bottom). The dashed rectangle represents the defender's orientation, and the length of the arrow along the direction of movement corresponds to the magnitude of the relative velocity.

(c) The initial velocity (at a separation of approximately 3 kilometers) is specified as a function of mission type. The actual velocity

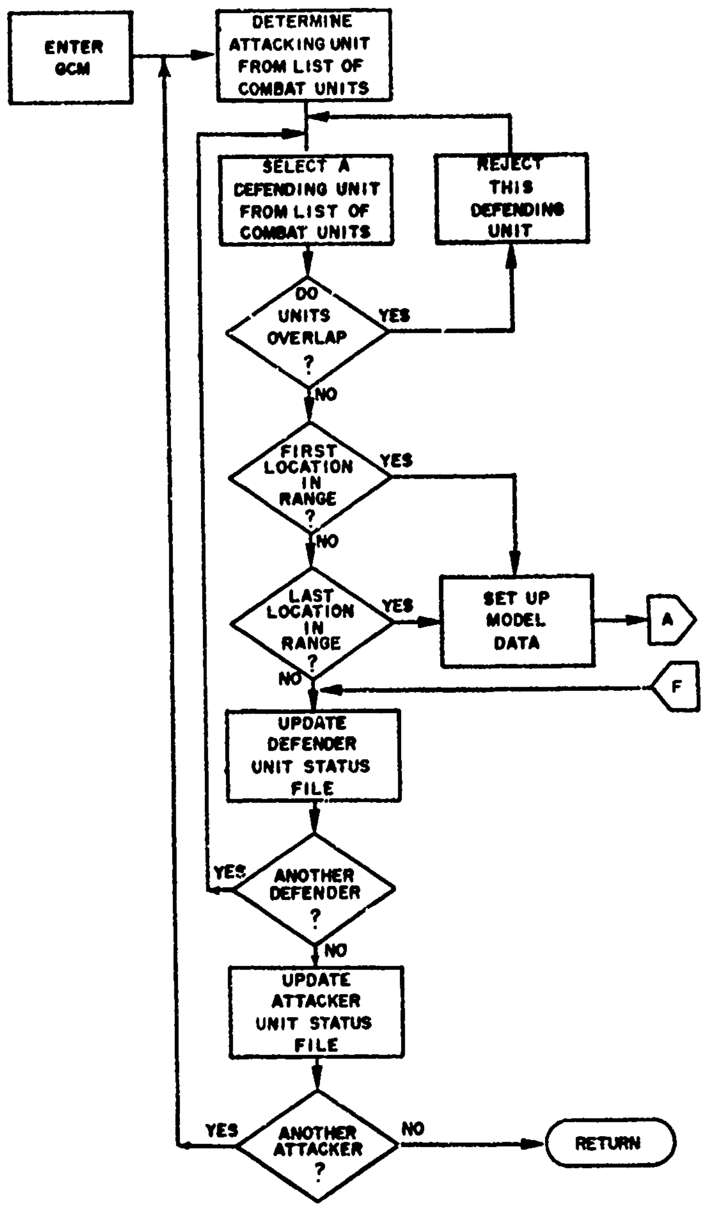

Figure 4-1. Ground Combat Model Flow Diagram: Model Driver
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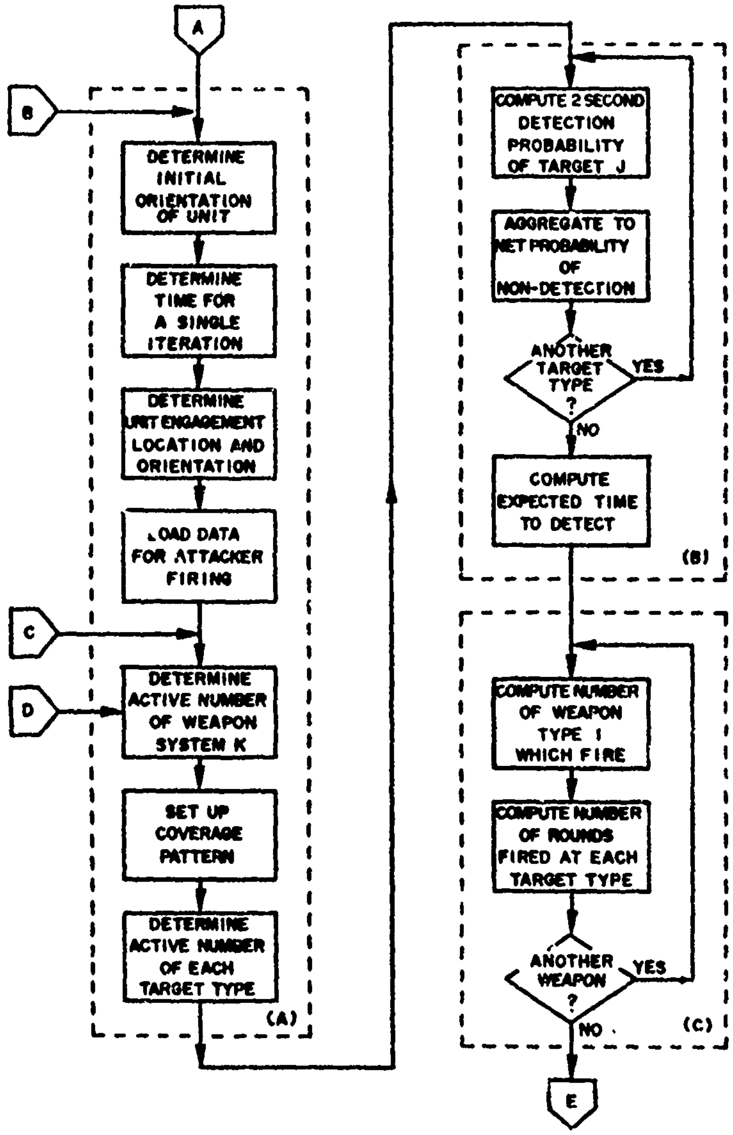


Figure 4-1. Ground Combat Model Flow Diagram: (A) Unit Geometry, (B) Target Acquisition, (C) Firepower Potential (continued)

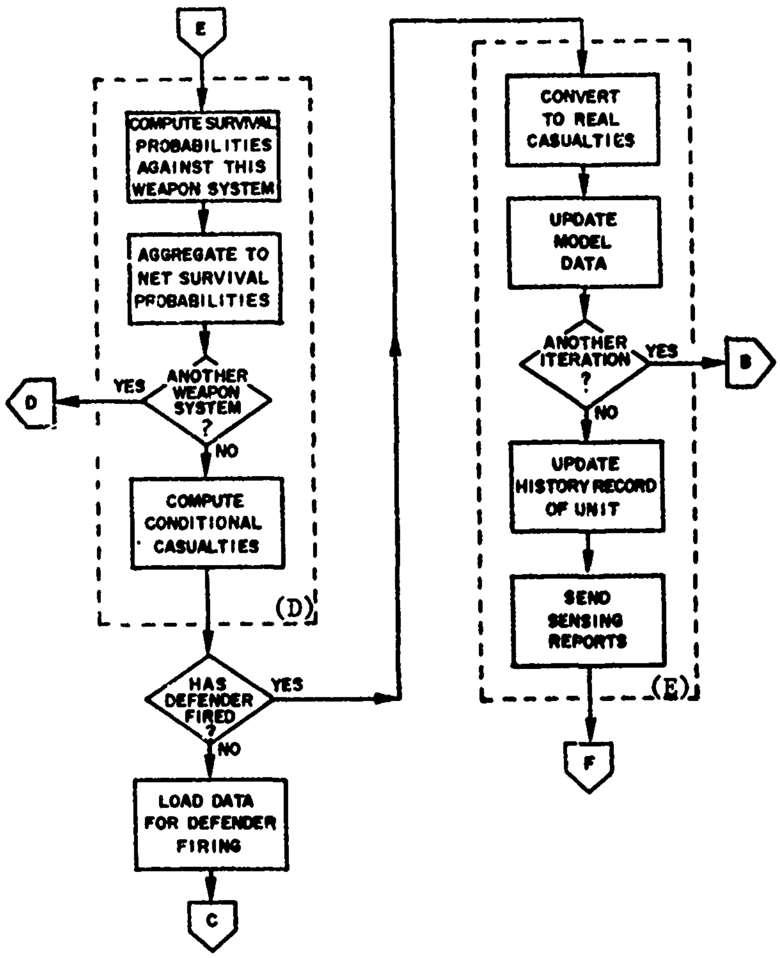


Figure 4-1. Ground Combat Model Flow Diagram: (D) Firepower Effectiveness, (E) Assessment (concluded)

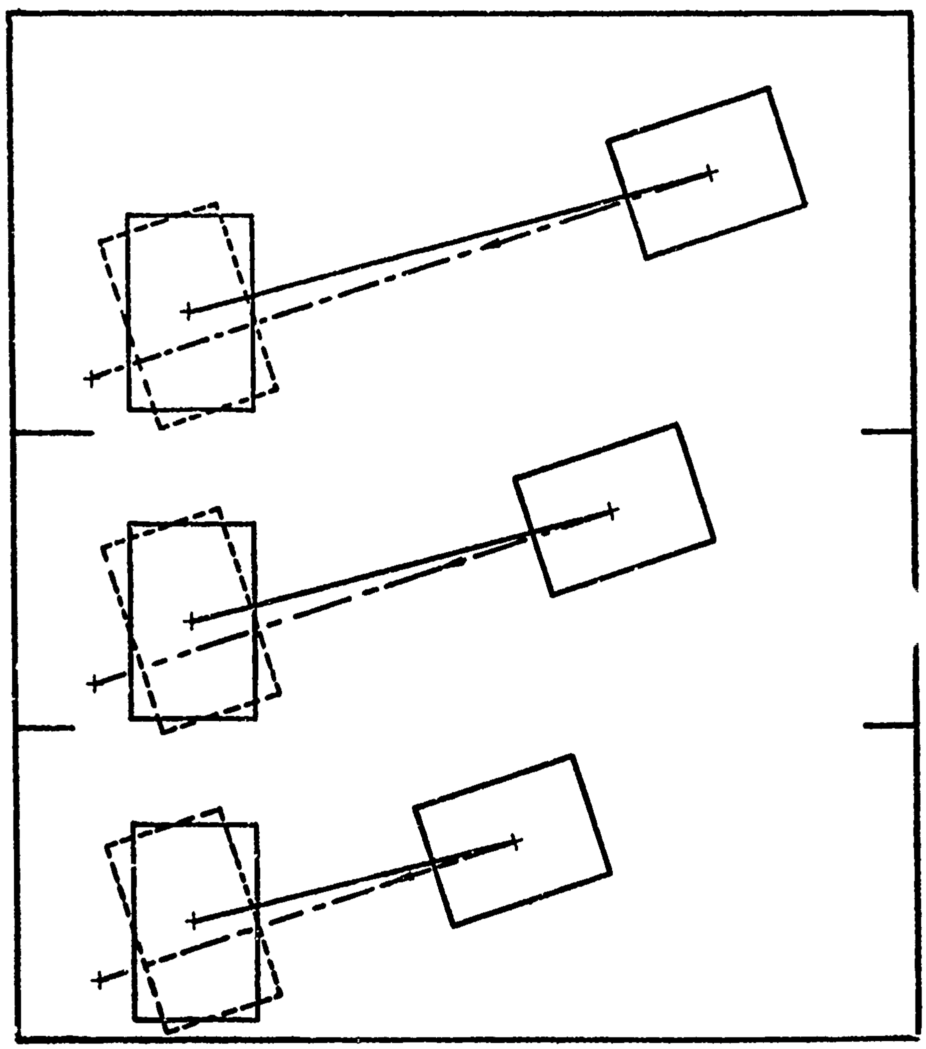


Figure 4-2. Unit Orientation and Movement

is determined by comparing the specified velocity with the mobility class rates from Movement Model data. If this specified velocity does not exceed the mobility class rate of any mobile weapon system in the front band of the unit, it is considered to be the actual initial velocity. If the specified velocity does exceed one or more mobility class rates, the slowest of these rates is substituted as the actual velocity of the unit. All moving weapon systems are considered to move at their maximum rate, the difference in unit and weapon system rates being attributable to a difference in postures among the elements. The following weapon system postures are considered:

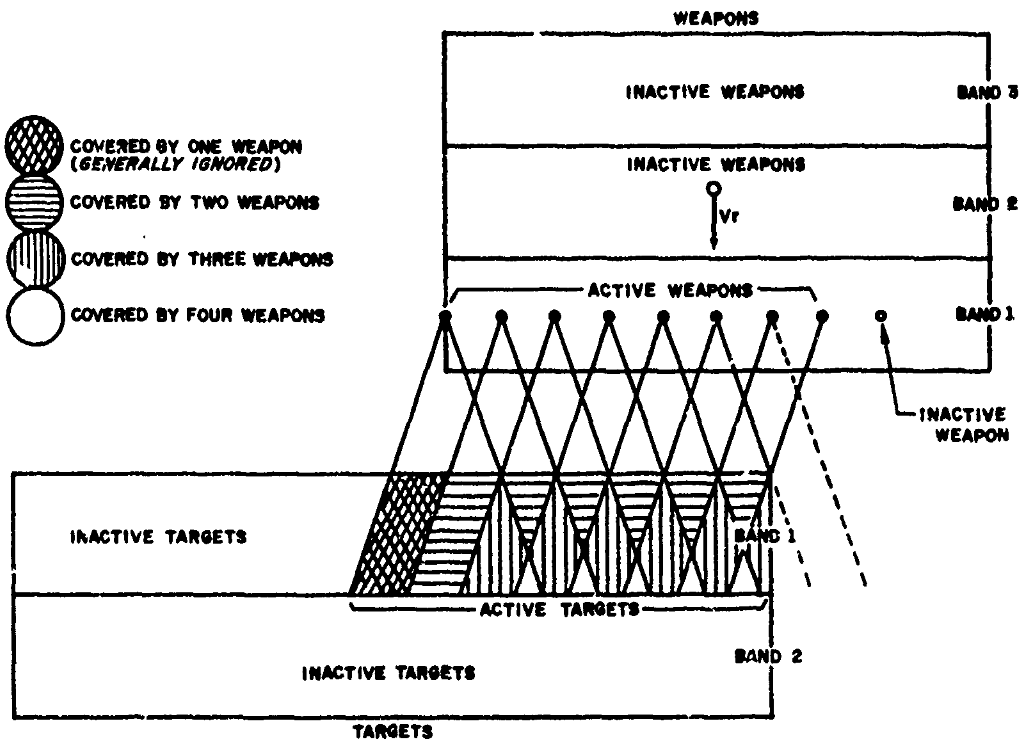
1. Stationary.

2. Advancing at its mobility class rate.

(d) Based upon the initial unit separation, relative velocity, and engagement duration the Unit Geometry Submodel determines the initial and projected final line of sight probabilities. A change in the line of sight probability of more than 0.1 is deemed unacceptable, and the model internally breaks the engagement duration into as many iterations as necessary to attain a probability of line of sight change of less than 0.1 for any iteration.

(e) The Unit Geometry Submodel then positions each unit midway between its initial and final locations for the engagement iteration being processed and assigns areas of responsibility to each weapon of the unit. Areas of responsibility are assigned to each weapon based upon the concept of mutual support. The scheme for area assignment is depicted in Figure 4-3. Figure 4-3 shows each actively engaged portion of the enemy unit covered by at least two weapons, with some areas covered by three or more weapons. (For computational efficiency the single coverage region, in the general case where 5 percent or less of a unit's rounds are delivered, is ignored, having a minor effect in the overall assessment of casualties.) This figure also demonstrates the model's capability of allowing a unit to concentrate its strength on a portion of the enemy unit. This capability is a result of the unit geometry orientation scheme.

(f) Once the active individual weapon's area of responsibility has been determined, the number of each target type active within this area is determined assuming uniformly distributed targets. Weapon systems and targets laterally displaced away from the edge of the enemy unit as illustrated in Figure 4-2 are not considered active. For each searching weapon system only nonzero priority target types are considered. (Weapon target priorities are discussed under firing doctrine below.) The number of targets within each weapon system's area of responsibility is then broken down to the number within that area that are covered two, three, or more times; and the range to the center of each type coverage region is calculated. Targets within each type coverage region are further distributed among possible activities in the two postures defined above. Four target postures are considered:



DIVWAG GROUND COMBAT MODEL, WEAPON-TARGET GEOMETRY

Figure 4-3. Weapon-Target Coverage Pattern for Laterally Offset U ts

1. Stationary and not firing.

2. Stationary and having fired one round.

3. Stationary and having fired two or more rounds.

4. Advancing and not firing.

(2) Target Acquisition:

(a) Target acquisition methodology is based upon modifications of the IMPWAG report (Reference 3). For each priority target type in each posture in each coverage region type, the probability that the observing weapon system is looking at this target is calculated. Given that the observer is looking at the target, the probability that the target's apparent contrast is detectable is calculated. Apparent contrast is a function of the target reflectance, vegetation, season of the year, time of day, and weather. Given that the observer is looking at the target and that its contrast is detectable, the probability that line of sight exists between the observer and target is calculated. Line of sight probability is calculated using an equation from a Ballistics Research Laboratory study, where the variable parameter has been expanded as a function of terrain, forestation, target type, and target posture. This line of sight parameter is discussed in detail in Volume VI, DIVWAG Data Requirements Definition.

(b) The probability that the observer detects nothing is calculated using these detection probabilities along with the numbers of each target type, in each posture, in each coverage region type that were calculated by the Unit Geometry Submodel.

(c) This probability is combined with the probability of nondetection of all other sensor types (appropriate to the existing conditions) at the observer's disposal. The capability of each other sensor type comes from fitting curves to existing experimental data. Finally, the probability that the observer detects at least one priority target is calculated. The expected value of the time to detect at least one target and fire is determined from this probability.

(d) Pinpoint probabilities are considered within the Ground Combat Model as follows. Based upon the total number of rounds fired by targets in postures 2 and 3, the probability an observer sees a stationary weapon that fires either one or two rounds is calculated. From this probability and a weapon's single-round pinpoint data (pregame input), the number of observers who pinpoint a target and do not visually observe any other target is calculated.

(3) Firepower Potential:

(a) To the expected value of the time to detect at least one priority target is added the average time to aim, fire, and deliver a round. This number is used with the line of sight probability and the number of weapons to determine the number of rounds this weapon system fires. Weapon target priorities are pregame input as follows: A number between zero and eight is assigned for each weapon target pair. Zero indicates that this weapon does not fire at this target type. One indicates that this target type is of highest priority for this weapon type. Increasing numbers indicate lower priority targets. Pinpointed targets are automatically considered lowest priorities. As ammunition expenditures reach varying percentages of the initial supply, lower priority targets are dropped from the list.

(b) Based upon the total number of rounds fired, the weapon target priorities, and the target acquisition information, the number of rounds fired at each target type in each posture in each coverage region type is determined.

(4) Firepower Effectiveness:

(a) The number of conditional casualties is calculated for each target type in each posture in each coverage region type based upon the total number of rounds fired at it. The probability of a hit and the kill probability given a hit are calculated by first determining the hit probability on a standard NATO target at this range (using linear interpolation between known values), using this hit probability to calcualte the weapon's error at this range, and finally calculating the hit probability based upon the target's presented area. The kill probability given a hit assumes a linear function in range with known slope and intercept. Applying the firepower potential within the framework of the coverage scheme (see Figure 4-3) to account for multiple hits, the number of conditional casualties is calculated.

(b) Based upon these conditional casualties the target's survival probability against each weapon type is calculated and aggregated into a net survival probability against all weapon types. The probability the target is killed by at least one weapon type is then calculated and applied to the number of active targets to generate conditional casualties for assessment.

(5) Assessment:

(a) The adjustment to real casualties is similar to the treatment of DIVTAG II, which provides a method of correcting for the simultaneity associated with return fire.

(b) The Unit Status File of each engaged unit is updated at the end of each engagement period to reflect all losses, expenditures, and consumption. Each unit is relocated to its coordinates attained by the end of the engagement period. The final movement rates of the engaged units are determined from the level of activity and placed on each Unit Status File.

(c) A sensing report is prepared and supplied to the Intelligence and Control Model. Estimates are made as follows:

1. Estimated movement rate does not include lateral movement.

2. Estimated x and y coordinates are the coordinates of the center of the engaged portion of the unit.

3. Estimated direction of movement is perpendicular to the front.

4. Number of items detected in tanks, APCs, other vehicles, and personnel (from the detection probabilities discussed under target acquisition, Paragraph (2) above).

5. Time of detection is the expected value of the time to detect (discussed under target acquisition, Paragraph (2) above).

(d) The sensing report of each unit is examined to determine if the target unit qualifies for mortar fire. If it does, an area fire event for mortars is scheduled.

b. DIVWAG Model Interface:

(1) External control of the initiation of a ground combat engagement is effected through the DSL commands ADVANCE, PREPARE, and ENGAGE. A list of all surface units to participate in a battle is included in the battle paragraph. An ADVANCE order is required for each attacking unit on this list, and a PREPARE order is required for each defending unit. These orders serve to define the proper unit widths, depths, band structures, and densities, as well as to provide each attacking unit with a velocity to enter the engagement. The system automatically issues the ENGAGE order 15 minutes following the game time when the front-to-front separation of any two opposing units listed in a battle paragraph has reached 3000 meters. The initial activation of the Ground Combat Model simulates the engagement that has occurred during this 15-minute interval and updates each participating unit's location, velocity, loss, expenditure, and consumption data to the current game time.

(2) Following every ground combat interval a sensing report is passed to the Intelligence and Control Model by each participating unit. Air ground or area fire events may be scheduled as a result of these reports. The interfaces of the automatic portions of the Area Fire/TACFIRE Model and

the Air Ground Engagement Model with the Intelligence and Control Model are described in detail in Chapter 3. Mortar fire events scheduled in Ground Combat, discussed in Paragraph 3, are assessed by the Area Fire/TACFIRE Model.

(3) The time interval of each subsequent activation of the Ground Combat Model is automatically scheduled subject to the conditions expressed in the battle paragraph and the scheduling of air ground engagements. The scheduled period is computed from a comparison of the loss rates generated during the last time interval and the battle conditions. If an air ground engagement is also scheduled to occur during this period for any one of the participating units, the scheduled period is reduced such that the Ground Combat Model simulates the engagement activity up to the time of the air ground engagement. The ground combat time interval is not affected by the scheduling of area fire events. It is assumed that the applied firepower of these models is not directed at common targets; if so, the effects of one model will dominate in the assessment.

(4) The above process is repeated until a battle condition is reached that terminates the engagement.

(5) The Ground Combat Model, interfaced with the balance of the DIVWAG Model, provides the following capabilities:

(a) Seventeen surface and air units for each force may engage in each battle.

(b) Each surface unit may employ eight types of weapon systems; e.g., tanks, APCs, and recoilless rifles. Sixteen weapon/ammunition combinations may be distributed among each unit's weapon systems.

(c) The model is capable of describing as many as 10 types of sensors, including unaided vision.

3. SUBMODEL SPECIFICATIONS:

a. General. The Ground Combat Model contains five major submodels that treat the areas of unit geometry, target acquisition, firepower potential, firepower effectiveness, and assessment within one pass through the model's unit-pair and time cycles. A driver routine is also required to establish the program interface between the Ground Combat Model and the DIVWAG Model, establishing the basic unit-pair cycle for the model dealing with one pair of opposing units at a time. To simplify any future requirements for model improvement the major submodels have been designed to operate independently of each other to the extent practicable. The integrated model does, however, require an extensive flow of information among the submodels. Figure 4-4 is a schematic of the flow of information among submodels; the essential content of this flow is identified below.

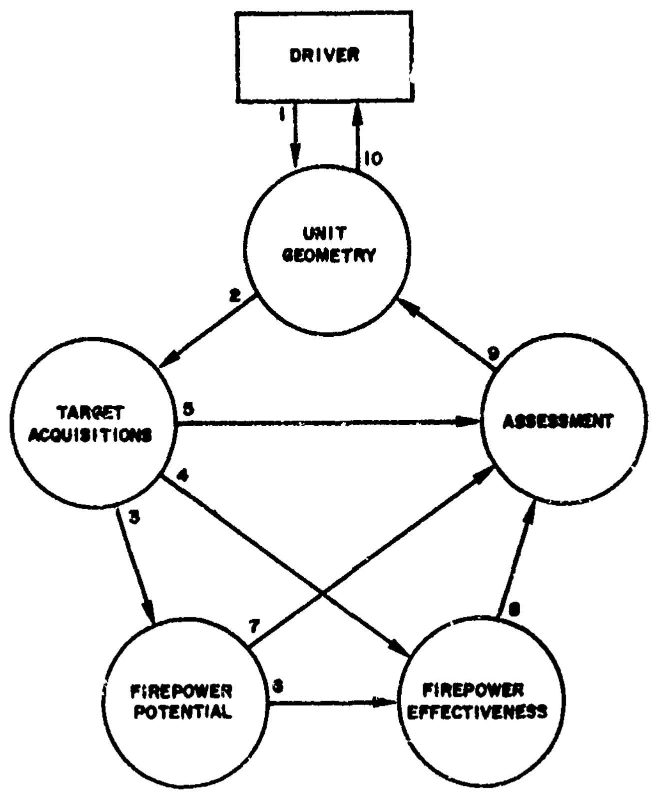


Figure 4-4. Ground Combat Model Information Flow Schematic

(1) The model driver supplies the Unit Geometry Model the following information:

(a) The Unit Status File of each engaged unit in attacker-defender pairs.

(b) The mobility class rate for each element in each unit.

(c) The visible range.

(d) The background reflectance within each unit.

(e) The line of sight parameter of each target element in each of two exposure postures.

(2) The Unit Geometry Submodel provides the Target Acquisition Submodel the following information:

(a) Number of actively engaged weapons of each type.

(b) Sensors employed by each weapon type.

(c) Duration of the engagement iteration.

(d) Area of responsibility for each weapon within the enemy unit resolved into double, triple, and quadruple coverage subareas.

(e) Range to each subarea.

(f) Number of actively engaged targets of each type within each subarea in each of four postures: advancing, stationary and not firing, stationary and have fired one round, and stationary and have fired two or more rounds.

(3) The Target Acquisition Submodel provides the detection probability for each weapon type against each target type in each posture in each subarea to the Firepower Potential Submodel.

(4) The Target Acquisition Submodel provides the line of sight probability for each target type in each posture in each subarea to the Firepower Effectiveness Submodel.

(5) The Target Acquisition Submodel provides the number of detections by forward observers, resolved into tanks, APCs, other vehicles, and personnel; and the time of detection to the Assessment Submodel.

(6) The Firepower Potential Submodel provides for each weapon type the number of rounds fired at each target type in each posture in each subarea to the Firepower Effectiveness Submodel.

(7) The Firepower Potential Submodel provides the total conditional rounds fired by each weapon type at each target type to the Assessment Submodel.

(8) The Firepower Effectiveness Submodel provides the conditional losses of each target type due to each weapon type to the Assessment Submodel.

(9) The Assessment Submodel provides the actual rounds fired, losses, and the sensing report to the Unit Geometry Submodel.

(10) The Unit Geometry Submodel provides all updated files and records to the driver.

b. Ground Combat Model Driver (Initiation Phase):

(1) General. With the exception of the sensing report that serves as the interface with the Intelligence and Control Model, all system interface requirements are created by the Ground Combat Model driver routine.

(2) Unit-Pair Selection and Cycling. The Ground Combat Model is designed to treat one pair of opposing units at a time. Figure 4-5 depicts a more general battle situation involving four surface units. In this example the initial activation of the Ground Combat Model would occur when unit A_2, the leading attacking unit, approaches within 3 kilometers of unit D_1, the defending unit. The ground combat event is scheduled 15 minutes after the time this occurs, and the first pass through the model simulates the engagement interactions of all four units during this 15-minute time interval. The Ground Combat Model driver breaks this single pass through the model into as many passes as are required to consider all attacker-defender pairs. In the example, Figure 4-5, three such passes are necessary. The order of the passes is unimportant and generally corresponds to the order in which the units are listed in the battle paragraph.

(3) Data Acquisition and Conversion. Following the selection of a pair of opposing units, the Ground Combat Model driver prepares the current data base for the model. The constant data describing weapon/target characteristics is obtained from one of two distinct data records corresponding to either Red attack and Blue defend or Blue attack and Red defend. The initial number of weapons and targets in the leading band of each of these two units is obtained from their Unit Status Files and the distribution of equipment within each unit. Environment files are accessed as indicated below.

(a) The roughness and vegetation (RV) index and forest type index are averaged over the leading band of each unit. If the average RV index is greater than 5, the terrain is considered poor; otherwise, it is considered good. If the average forest index is less than 0.5, the terrain is considered to be unforested; otherwise, it is forested. The terrain and forest type at the site of each unit is then used to determine input values for the line

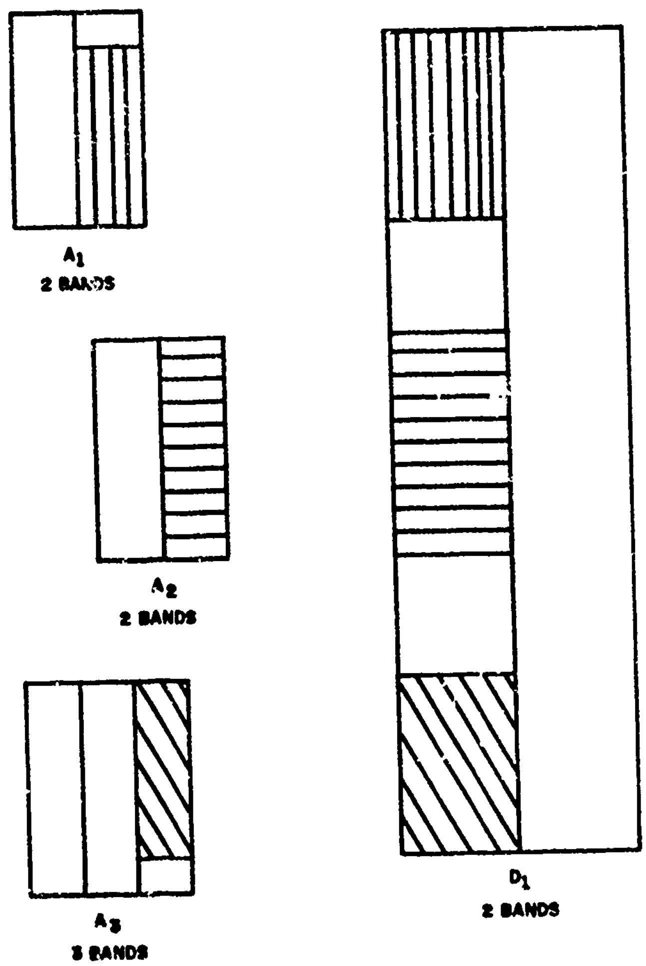


Figure 4-5. Multiple Unit Engagement

of sight parameters for each target. The average index is used to select the appropriate background reflectance.

(b) The visible range is obtained from the weather file.

(c) The sky-ground ratio (i.e., the relative brightness of the horizon and background) is determined by interpolating between values corresponding to looking into the sun and looking away from the sun, based upon the current time of day or night and the positions of the units.

c. Unit Geometry Submodel:

(1) General:

(a) The primary function of the Unit Geometry Submodel is to determine the portion of attacking unit and the portion of defending unit which engage in combat with one another. Referring to Figure 4-5, attacking unit A_2 engages only a portion of unit D_1, and D_1 is simultaneously concentrating part of its force against unit A_1 and part against A_2. The front of that portion of the unit that is actively engaged within each attacker-defender pair, the engagement front, is determined by the Unit Geometry Submodel. The submodel also computes the front-to-front separation of the units.

(b) The Unit Geometry Submodel also has the capability of breaking the scheduled combat interval into smaller time periods that can be modeled with greater accuracy. Because most combat functions depend on the probability of line of sight, a change in line of sight probability of more than 0.1 in a single pass through the model is deemed unacceptable for satisfactory results. If the relative position and movement of the units is such that the line of sight probability changes by more than 0.1 in the scheduled pass through the model, the Unit Geometry Submodel divides that one pass into as many internal iterations as necessary to maintain a change of less than 0.1 in the line of sight probability within each iteration.

(c) Within each iteration the Unit Geometry Submodel controls the flow through the other submodels for two distinct phases corresponding to the firing attack unit and the firing defend unit. For each phase, the coverage pattern of each weapon system type within the firing unit is calculated. This submodel also determines the number of each type target within each type coverage region.

(2) Front-to-Front Separation:

(a) Figure 4-6, an enlargement of a portion of Figure 4-2. defines the variables used to determine the front-to-front separation and the engagement front. The variables in Figure 4-6 are described below:

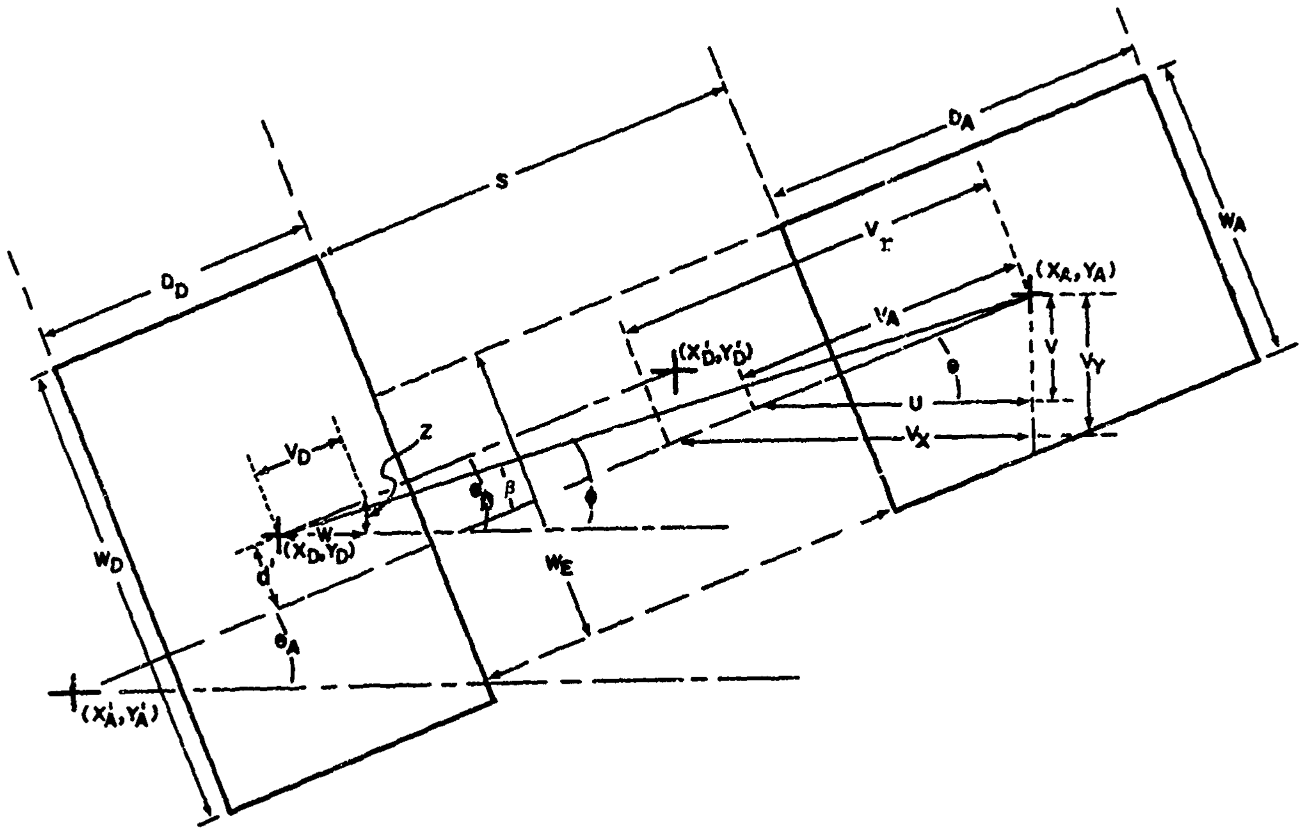


Figure 4-6. Unit Orientation Variables

(X_A, Y_A) = Attacker's initial position

(X_D, Y_D) = Defender's initial position

(X_A', Y_A') = Attacker's objective position

(X_D', Y_D') = Defender's objective position

v_A = Attacker's initial velocity

v_D = Defender's initial velocity

u = X-component of v_A

v = Y-component of v_A

w = X-component of v_D

z = Y-component of v_D

v_r = Relative velocity

v_x = X-component of v_r

v_y = Y-component of v_r

D_A = Depth of attacker

D_D = Depth of defender

w_A = Width of attacker

w_D = Width of defender

S_i = Front-to-front separation

w_e = Engagement front

(b) Figure 4-6 shows that the front-to-front separation may be related to the distance between the units' centers, C, by Equation 4-1:

$$S_i = C \cos \beta - (D_A + D_D) / 2 \qquad (4\text{-}1)$$

where β is the angle between the units' relative velocity and the line connecting their centers. β must be related to known variables to complete the calculation.

(c) Defining θ as the angle between the relative velocity and th x-axis and ϕ as the angle between the line connecting the units' centers and the x-axis, further examination of the figure reveals the following relation between β, θ, and ϕ:

$$\beta + (90 - \theta) = 90 - \phi \tag{4-2a}$$

or:

$$\beta = \theta - \phi \tag{4-2b}$$

(d) In order to find θ it is necessary to determine the relative velocity. From Figure 4-6 it is seen that the velocity components of the two units can be expressed by Equations 4-3:

$$u = v_A \cos\theta_A \tag{4-3a}$$

$$v = v_A \sin\theta_A \tag{4-3b}$$

$$w = v_D \cos\theta_D \tag{4-3c}$$

$$z = v_D \sin\theta_D \tag{4-3d}$$

where θ_A and θ_D are defined in the figure. The components of the relative velocity are the difference of the individual units' components as expressed in Equations 4-4:

$$v_x = u - w \tag{4-4a}$$

$$v_y = v - z \tag{4-4b}$$

and θ can be determined from Equation 4-5:

$$\theta = \tan^{-1} (v_y / v_x) \tag{4-5}$$

Substituting Equations 4-3 into Equations 4-4 and the result into Equation 4-5 leads to the expression of θ given in Equation 4-6.

$$\theta = \tan^{-1} [(v_A \sin\theta_A - v_D \sin\theta_D) / (v_A \cos\theta_A - v_D \cos\theta_D)] \quad (4\text{-}6)$$

(e) The angles ϕ, θ_A and θ_D can be expressed in terms of the units' initial and objective coordinates using Equations 4-7:

$$\phi = \tan^{-1} [(Y_A - Y_D) / (X_A - X_D)] \quad (4\text{-}7a)$$

$$\theta_A = \tan^{-1} [(Y_A - Y_A') / (X_A - X_A')] \quad (4\text{-}7b)$$

$$\theta_D = \tan^{-1} [(Y_D' - Y_D) / (X_D' - X_D)] \quad (4\text{-}7c)$$

Substituting Equation 4-2b into Equation 4-1 and using the trigonometric identity $\cos(x-y) = \cos x \cdot \cos y + \sin x \cdot \sin y$, S_i may be expressed by Equation 4-8:

$$S_i = C (\cos\theta \cos\phi + \sin\theta \sin\phi) - (D_A + D_D) / 2 \quad (4\text{-}8)$$

Using Equations 4-4, 4-5, and the trigonometric identity $\cos x = 1 / \sqrt{1+\tan^2 x}$, $\cos\theta$ is expressed by Equation 4-9:

$$\begin{aligned} \cos\theta &= 1 / \sqrt{1 + \tan^2\theta} \\ &= (u - w) / \sqrt{(u - w)^2 + (v - z)^2} \\ &= (u - w) / \sqrt{v_A^2 + v_D^2 - 2(uw + vz)} \end{aligned} \quad (4\text{-}9)$$

By using the same identity and Equation 4-7a, cos ϕ can be expressed by Equation 4-10:

$$\cos\phi = 1 / \sqrt{1 + \tan^2\phi}$$

$$= (X_A - X_D) / \sqrt{(X_A - X_D)^2 + (Y_A - Y_D)^2}$$

$$= (X_A - X_D) / C \qquad (4\text{-}10)$$

where C is the distance between the units' centers. Using the trigonometric identity $\sin x = 1 / \sqrt{(1 / \tan^2 x) + 1}$, Equations 4-4, 4-5, and 4-7a lead to similar expressions for $\sin\theta$ and $\sin\phi$:

$$\sin\theta = (v - z) / \sqrt{v_A^2 + v_D^2 - 2(uw + vz)} \qquad (4\text{-}11)$$

$$\sin\phi = (Y_A - Y_D) / C \qquad (4\text{-}12)$$

(f) Finally, substituting Equations 4-9 through 4-12 into Equation 4-8, S_i is expressed by Equation 4-13:

$$S_i = [(X_D - X_A)(u - w) + (Y_D - Y_A)(v - z)]$$

$$/ \sqrt{v_A^2 + v_D^2 - 2(uw + vz)} - (D_A + D_D) / 2 \qquad (4\text{-}13)$$

where u, v, w, and z are calculated from Equations 4-3 to be the following:

$$u = v_A(X_A' - X_A) / \sqrt{(X_A' - X_A)^2 + (Y_A' - Y_A)^2} \qquad (4\text{-}14a)$$

$$v = v_A(Y_A' - Y_A) \Big/ \sqrt{(X_A' - X_A)^2 + (Y_A' - Y_A)^2} \qquad (4\text{-}14b)$$

$$w = v_D(X_D' - X_D) \Big/ \sqrt{(X_D' - X_D)^2 + (Y_D' - Y_D)^2} \qquad (4\text{-}14c)$$

$$z = v_D(Y_D' - Y_D) \Big/ \sqrt{(X_D' - X_D)^2 + (Y_D' - Y_D)^2} \qquad (4\text{-}14d)$$

(g) If the value of S_i is negative the engage order is ignored. If the value of S_i is positive but less than or equal to 50 meters a check is made to determine if the units are attempting to get closer together. If the separation is decreasing with time, S_i is set to 50 meters and both units are stopped. If the separation is increasing with time, the value of S_i in Equation 4-13 is used.

(3) Internal Iterations:

(a) Based upon the relative velocity, v_r, of the two units calculated by Equation 4-15:

$$v_r = \sqrt{(u - w)^2 + (v - z)^2} \qquad (4\text{-}15)$$

their initial separation given by Equation 4-13, and the engagement duration, t_e, the final front-to-front separation, S_f, is calculated using Equation 4-16:

$$S_f = \max(S_i - v_r t_e, S_1) \qquad (4\text{-}16)$$

The maximum is used in Equation 4-16 to prevent the units from getting closer together than S_1, where S_1 is the limiting separation which can be treated adequately by the model. Model design requires S_1 to be greater than zero; however, the best choice must be determined from model testing. The current version of the Ground Combat Model imposes a limiting separation of not less than 50 meters.

(b) In Equation 4-16 t_e is first equated to the scheduled engagement duration, t_s. The line of sight probabilities at ranges corresponding to both the initial and final separations are computed using Equation 4-17 from the Ballistics Research Laboratory study, Terrain and Ranges of Tank Engagements (Reference 2).

$$P_{LOS}(r) = (1 + 2r / \bar{r})\, e^{-2r / \bar{r}} \qquad (4\text{-}17)$$

A check is then made to determine if the resulting line of sight probabilities satisfy the inequality of Equation 4-18:

$$\left| P_{LOS}(S_f) - P_{LOS}(S_i) \right| \leq 0.1 \qquad (4\text{-}18)$$

If Equation 4-18 is satisfied the scheduled engagement duration is treated by a single pass through the Acquisition and Firepower Submodels.

(c) Figure 4-7 is a typical plot of P_{LOS} versus range, using a value of 0.6 kilometers for $\bar{r}$ in Equation 4-17. An examination of this figure shows that in regions I and III there is no significant change in P_{LOS} for substantial changes in range. It will be shown in the descriptions of the Acquisition and Firepower Submodels that the level of combat activity is strongly influenced by the probability of line of sight. Accordingly a situation in which the separation and movement of the engaged units corresponds to a substantial portion of region II in Figure 4-7 is treated as a series of smaller movements.

(d) If Equation 4-18 is not satisfied, t_e is equated to $t_s / 2$ in Equation 4-16 and another test is made of the inequality of Equation 4-18. This process is repeated by incrementing n until some $t_e = t_s / n$ is found which satisfies the inequality. This value of t_e represents the time interval of the first iteration through the remaining submodels. The remaining scheduled duration of the engagement is determined using Equation 4-19:

$$t_s' = t_s - t_e \qquad (4\text{-}19)$$

Following the assessment of the first iteration the entire process beginning with the calculation of front-to-front separation using updated variables is repeated. The Unit Geometry Submodel continues to generate successive iterations through the model until the requested engagement duration has been completed.

(4) Engagement Separation, Velocity and Front:

(a) For each iteration the engagement separation is computed using Equation 4-20 which places the units mid-way between their initial and final locations:

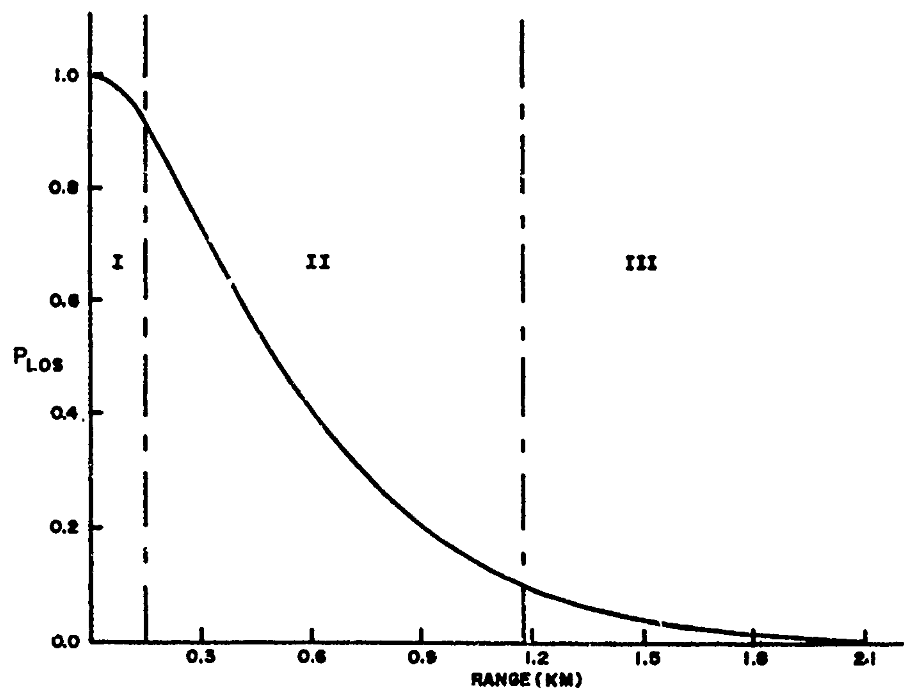


Figure 4-7. Line of Sight Probability versus Range (km) for $\bar{r}$ = 0.6 km

$$S_e = (S_i + S_f) / 2 \qquad (4\text{-}20)$$

(b) Since S_f of Equation 4-16 may be limited by the value S_1, the unit's velocities are redefined to force them to stop at a separation of 50 meters. The engagement relative velocity is defined by Equation 4-21 and is equal to v_r unless Equation 4-16 was limited by S_1. Both the attacking and defending velocities are multiplied by the ratio v_{re} / v_r to determine the engagement velocities.

$$v_{re} = (S_i - S_f) / t_e \qquad (4\text{-}21)$$

(c) The engagement front is determined by examining its dependence on the value of d' defined in Equation 4-22 and illustrated in Figure 4-6.

$$\begin{aligned} d' &= C \sin\beta \\ &= C\sqrt{1 - \cos^2\beta} \end{aligned} \qquad (4\text{-}22)$$

Substituting Equation 4-1 for $\cos\beta$ and evaluating the result at the engagement separation, S_e, leads to Equation 4-23:

$$d' = \sqrt{C^2 - [S_e + (D_A + D_D) / 2]^2} \qquad (4\text{-}23)$$

A close examination of Figure 4-6 shows that when d' attains the value (1 / 2) $(w_A + w_D)$ the units are laterally offset from one another and the engagement front is zero. As long as d' is less than one half the absolute difference of the units' fronts, the engagement front is equal to the front of the more narrow unit. In between these limiting values the engagement front is linear with respect to d'. These three cases are listed below and illustrated in Figure 4-8.

Case 1. $d' \geq 1/2\ (w_A + w_D)$, $w_e = 0$

Case 2. $1/2\ |w_A - w_D| < d' < 1/2\ (w_A + w_D)$, w_e linear in d'

Case 3. $d' \leq 1/2\ |w_A - w_D|$, $w_e = \min \{w_A, w_D\}$

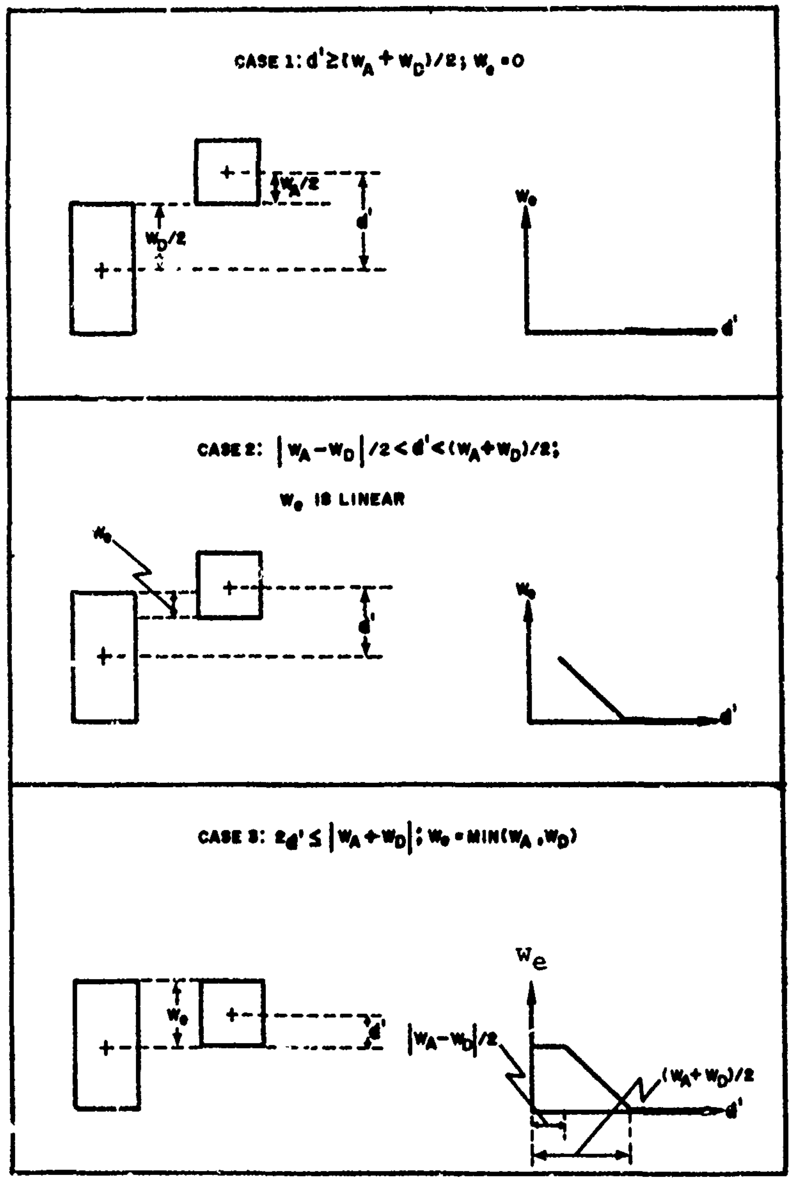


Figure 4-8. Relationship Between the Engagement Frontage and the Variable d'

Imposing the boundary conditions provided by Cases 1 and 3 above to the general form $w_e = md' + b$, where m and b are the slope and intercept, the solution for Case 2 is provided by Equation 4-24:

$$w_e = 2\min\left\{w_A, w_D\right\} [d' - (w_A + w_D) / 2] / [\left|w_A - w_D\right| - (w_A + w_D)] \qquad (4\text{-}24)$$

The general equation to apply to all three cases takes the form of Equation 4-25:

$$w_e = 2\min(w_A, w_D) \min[\max(d', |w_A - w_D| / 2), (w_A + w_D) / 2)] \qquad (4\text{-}25)$$

$$- [(w_A + w_D) / 2)] / [|w_A - w_D| - (w_A + w_D)]$$

Making use of the identity of Equation 4-26 and pulling the factor of 1/2 outside the brackets, the final form of the equation to compute the engagement front reduces to Equation 4-27:

$$|x - y| - (x + y) = -2\min(x,y) \qquad (4\text{-}26)$$

$$w_e = (w_A + w_D - \min\left\{\max[2d', |w_A - w_D|], w_A + w_D\right\})/2 \quad (4\text{-}27)$$

The front computed using Equation 4-27 is shown as shaded regions in Figure 4-5 for each of three units attacking simultaneously.

(5) Coverage Pattern:

(a) Figure 4-9 is an enlargement of a portion of the target unit of Figure 4-10, and both serve to define the variables used to determine the areas and ranges to each type of coverage region. The area of each type coverage region is required to determine the portion of the target unit and the number of targets with which each weapon can interact. The range to each type coverage region is required to determine target acquisition capabilities that depend strongly on the observer-target separation. Although the problem is not addressed explicitly, an angle of responsibility (γ, in Figure 4-10) acknowledges interweapon communications by allowing a weapon to acquire a target outside this angle and not fire at it. In Figure 4-10, S_e is the separation, defined by Equation 4-20. In this example the weapon unit width, w_W, the target unit width, w_T, and the engagement front, w_e, are equal.

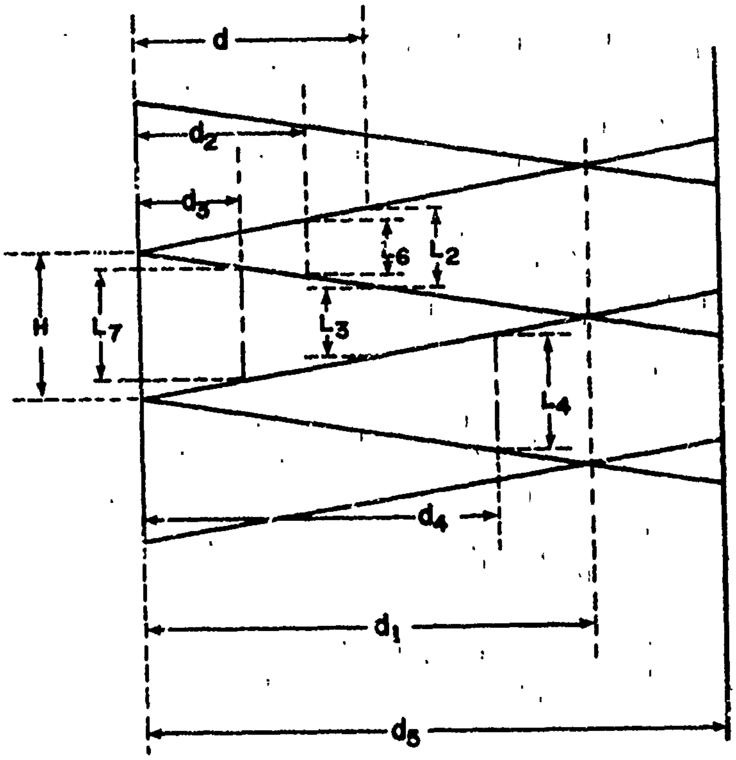


Figure 4-9. Coverage Pattern Variables

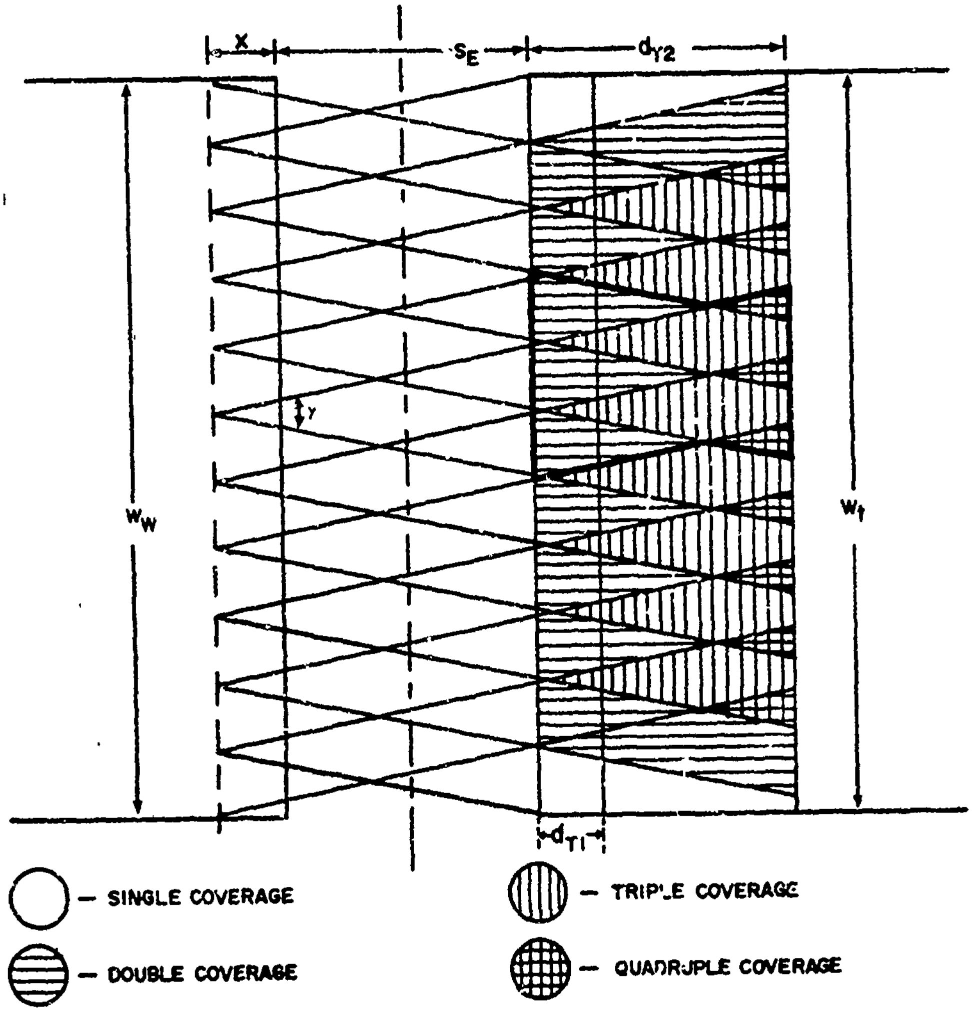


Figure 4-10. Coverage Pattern Variables

w_e is defined in Equation 4-27. The depth of the target unit's leading band is d_T, where d_{T1} and d_{T2} show the coverage pattern in two possible unit sizes. If f_{i1} is the fraction of weapon system i in band 1 and N_i is the initial number of weapon system i on hand, then the number of weapon system i which is active is given by Equation 4-28:

$$n_i = f_{i1} N_i w_e / w_W \tag{4-28}$$

n_i is truncated to an integer value and the interweapon spacing, H, is computed using Equation 4-29:

$$H = w_e / (n_i - 1) \tag{4-29}$$

The n_i active weapons are assumed to be equally spaced along a line a depth X into the weapon unit. The depth X is related to the expected value of the line of sight probability by Equation 4-30:

$$X = \int_{S_e}^{Se + d_W} P_{LOS}(r)\, dr \tag{4-30}$$

Substituting Equation 4-17 for $P_{LOS}(r)$ and performing the integration yields Equation 4-31:

$$X = (S_e + \bar{r})\, e^{-2S_e/\bar{r}} - (S_e + d_W + \bar{r})\, e^{-2(S_e + d_W)/\bar{r}} \tag{4-31}$$

where $\bar{r}$ is the line of sight parameter and d_W is the depth of the front band of the weapon unit. To prevent placing the weapons behind the center of the front band, X is redefined by Equation 4-32:

$$X = \mathrm{Min}(X,\ d_W/2) \tag{4-32}$$

Figure 4-9 shows that the first intersection of coverage lines within the target unit occurs at a depth into the target unit, labeled d_1 in Figure 4-9, of $(1/2)\ (S_e + X)$. Calculation of the coverage areas is most conveniently broken into two cases: $0 \leq d_T \leq d_1$ and $d_1 \leq d_T \leq 2d_1$.

1. The distance d in Figure 4-9 corresponds to the case where the first intersection of coverage lines occurs behind the target unit's leading band. In this case no portion of the unit is covered by more than three weapons. The area of one triple coverage region is:

$$A_3 = dL_2 / 2 \qquad (4\text{-}33)$$

but from similar triangles:

$$L_2 / d = H / (S_e + X) / 2 \qquad (4\text{-}34)$$

Solving Equation 4-34 for L_2 and substituting the result into Equation 4-33 leads to Equation 4-35:

$$A_3 = H \cdot d^2 / (S_e \cdot X) \qquad (4\text{-}35)$$

The area of one double coverage region is:

$$A_2 = [(L_3 + H) / 2]d \qquad (4\text{-}36)$$

but from the figure:

$$L_2 + L_3 = H \qquad (4\text{-}37)$$

Solving Equation 4-37 for L_3, substituting Equation 4-34 for L_2 and inserting the result into Equation 4-36 leads to Equation 4-38:

$$\begin{aligned} A_2 &= (H - L_2 + H) \cdot d / 2 \\ &= H \cdot d - 1/2 \; \frac{H \cdot d^2}{1/2(S_e + X)} \\ &= H[d - d^2 / (S_e + X)] \qquad (4\text{-}38) \end{aligned}$$

In this case there is no quadruple coverage region within the leading band and hence $A_4 = 0$. The ranges to the various coverage regions are taken to be the distances from the observer to the points within each region where there are as many targets within the range as beyond it. Since targets are uniformly distributed within each region, the depth into each region which

divides the area in half is required. From Figure 4-9 similar triangles relate d_2, L_6, d, and L_2 according to Equation 4-39:

$$d / d_2 = L_2 / L_6 \tag{4-39}$$

The requirement of dividing the area in half is expressed in Equation 4-40:

$$L_6 d_2 / 2 = (dL_2 / 2) / 2 \tag{4-40}$$

Solving Equation 4-39 for L_6, substituting into Equation 4-40, and solving for d_2 leads to Equation 4-41:

$$\begin{aligned} (L_2 d_2 / d)(d_2 / 2) &= dL_2 / 4 \\ d_2^2 &= d^2 / 2 \\ d_2 &= d / \sqrt{2} \\ &= 0.707d \end{aligned} \tag{4-41}$$

Thus, the range to a triple coverage region is given by Equation 4-42:

$$R_3 = S_e + X + 0.707 \cdot d \tag{4-42}$$

It is next required to determine the distance d_3 that divides the trapezoid into two equal areas. Mathematically this requirement is stated in Equation 4-43:

$$(L_7 + H) \cdot d_3 / 2 = [(L_3 + H) \cdot d / 2] / 2 \tag{4-43}$$

Substituting Equations 4-34 and 4-37 for L_3 into Equation 4-43 yields Equation 4-44:

$$(L_7 + H) \cdot d_3 = H[d - d^2 / (S_e + X)] / 2 \tag{4-44}$$

From Figure 4-9 it is seen that Equation 4-45 relates d_3 to L_7:

$$(S_e + X) / 2H = [(S_e + X) / 2 - d_3] / L_7 \qquad (4\text{-}45)$$

Solving this equation for L_7 and substituting the result into Equation 4-44 leads to the expression in Equation 4-46 for d_3:

$$d_3{}^2 - (S_e + X) \cdot d_3 + (S_e + X)\ (d - d^2 / [S_e + X]) = 0 \qquad (4\text{-}46)$$

This equation is immediately solvable using the quadratic equation yielding Equation 4-47:

$$d_3 = 1/2\ (S_e + X) - \sqrt{1/4\ (S_e + X)^2 - (S_e + X)\ d / 2 + d^2 / 2} \qquad (4\text{-}47)$$

where inspection of the result led to the choice of the minus sign. Thus R_2 is given by Equation 4-48:

$$R_2 = 3\ (S_e + X) / 2 - \sqrt{(S_e + X)^2 - 2(S_e + X) \cdot d + 2d^2} / 2 \qquad (4\text{-}48)$$

2. The distance d_5 in Figure 4-9 corresponds to the case where $d_1 \leq d_T \leq 2d_1$. In this case part of the target unit is covered by four weapons. The area of the double coverage region is constant at the value it has for $d = d_1$. Substituting $d_1 = (S_e + X) / 2$ into Equation 4-38 leads to Equation 4-49:

$$A_2 = H\ (S_e + X) / 4 \qquad (4\text{-}49)$$

The area of a triple coverage region is the sum of the areas of the triangle defined by $d = d_1$ and the remaining trapezoid to the right of this line, as indicated in Equation 4-50:

$$A_3 = [H\ (S_e + X) / 2] / 2 + H[\ d - (S_e + X)$$

$$/ 2 - [d - (S_e + X) / 2]^2 / (S_e + X)] \qquad (4\text{-}50)$$

The second term in Equation 4-50 results from substituting $d - (S_e + X) / 2$ for d in Equation 4-38, which described a similar trapezoid. Equation 4-50 may be simplified to the form of Equation 4-51:

$$A_3 = H[2d - d^2 / (S_e + X) - (S_e + X) / 2] \qquad (4\text{-}51)$$

There is a portion of the target unit covered by four observers. The area of the quadruple coverage region is that of a triangle identical in shape to the triple coverage region of Case 1. In this case the quadruple coverage area may be expressed by Equation 4-52:

$$A_4 = H[d - (S_e + X) / 2]^2 / (S_e + X) \qquad (4\text{-}52)$$

that results from the substitution of $d - (S_e + X) / 2$ for d in Equation 4-35. The range to the double coverage triangular area is determined by letting $d = (S_e + X) / 2$ in Equation 4-48. The result is expressed in Equation 4-53:

$$R_2 = 1.146\ (S_e + X) \qquad (4\text{-}53)$$

To determine R_3 it is necessary to find d_4 that divides the area formed by the triple coverage triangle and trapezoid in half, as expressed in Equation 4-54:

$$L_4 d_4 / 2 = H[2d - d^2 / (S_e + X) - (S_e + X) / 2] /2 \qquad (4\text{-}54)$$

From the figure it is seen that Equation 4-55 relates L_4 to L_5.

$$L_4 / d_4 = H / (S_e + X) / 2 \qquad (4\text{-}55)$$

Solving for L_4 and substituting into Equation 4-54 yields, after some rearrangement, Equation 4-56:

$$d_4 = \sqrt{d(S_e + X) - d^2 / 2 - (S_e + X)^2 / 4} \qquad (4\text{-}56)$$

Thus, R_3 can be determined by Equation 4-57:

$$R_3 = S_e + X + \sqrt{d(S_e + X) - d^2 / 2 - (S_e + X)^2 / 4} \qquad (4\text{-}57)$$

R_4 is very similar to the R_3 for Case 1 and is expressed by Equation 4-58:

$$R_4 = 3\ (S_e + X) / 2 + .707\ [d - (S_e + X) / 2]$$

$$= 1.146\ (S_e + X) + .707 \cdot d \qquad (4\text{-}58)$$

(b) Referring to Figure 4-10 it is seen that there are a total of n_i-1 double coverage regions, n_i-2 triple coverage regions, and n_i-3 quadruple coverage regions. Thus, the total area covered is given by Equation 4-59:

$$A = (n_i-1)\ A_2 + (n_i-2)\ A_3 + (n_i-3)\ A_4 \qquad (4\text{-}59)$$

(c) The angle of responsibility for an individual weapon is given by Equation 4-60:

$$\gamma = 2 \cdot \tan^{-1} [H / (S_e + X)] \qquad (4\text{-}60)$$

(6) Target Distribution:

(a) The number of active targets is determined as for active weapons and expressed by Equation 4-61:

$$m_j''' = f_{j1}\ m_j\ W_e/W_T \qquad (4\text{-}61)$$

where:

m_j''' = number of active targets

f_{j1} = fraction of targets j in band 1

m_j = initial number of targets j

W_e = engagement front

W_T = target unit width

Since it is possible that the front band of the target unit is deeper than Case 2 above allows (i.e., $D_T > S_e + X$), a further correction to the active targets is required as indicated in Equation 4-62:

$$m_j'' = m_j''' \cdot \mathrm{Min}\,(S_e + X,\ D_T)\ /\ D_T \qquad (4\text{-}62)$$

(b) Since these m_j active targets are uniformly distributed throughout the area given in Equation 4-59, the number of active targets per coverage section can be expressed by Equation 4-63:

$$m_{jk} = \frac{m_j'' \cdot A_k}{A}\ ;\ k = 2,\ 3,\ 4 \qquad (4\text{-}63)$$

where A was defined by Equation 4-59.

(c) These targets are further subdivided into stationary and moving postures. If the target unit velocity is v_T and the mobility class rate for target j is v_j, then the fraction of targets moving can be expressed by Equation 4-64:

$$f_1 = v_T\ /\ v_j \qquad (4\text{-}64)$$

Similarly, the stationary fraction is given by Equation 4-65:

$$f_2 = 1 - f_1 = 1 - v_T\ /\ v_j \qquad (4\text{-}65)$$

Thus, the number of targets of type j in posture 1 in a single coverage section of type k is given by Equation 4-66:

$$m_{jkl} = m_{jk} \cdot f_l : \begin{cases} j = 1,2,\ldots,8 \\ k = 2,3,4 \\ l = 1,2 \end{cases} \qquad (4\text{-}66)$$

where m_{jk} was defined by Equation 4-63.

d. Target Acquisition Submodel:

(1) General:

(a) The Target Acqusition Submodel calculates the time dependent probability of a single observer detecting a single target using unaided vision. This probability is calculated for each target type in each posture at the range corresponding to the center of each type coverage region.

(b) The submodel also calculates the probability of detection for other sensor types, assuming a range dependent detection function of the form $P_D(r) = ae^{-br}$, where the values of a and b must be determined from experimental data. These detection functions are further assumed to have a time dependence of the form $P_D(r,t) = 1 - (1 - P_D(r))^t$ in order to meaningfully combine them with the unaided visual detection probabilities.

(c) From these combined detection probabilities the submodel calculates the expected value of the time to detect at least one priority target. The detection probabilities against all target, posture, range combinations are converted to reflect their values at this time.

(d) The probability of pinpointing (i.e., detecting evidence of the target having fired) each type stationary target is calculated by the submodel based upon the number of targets that have recently fired either one or two rounds and experimental pinpoint probability data.

(2) Unaided Vision:

(a) Unaided visual target detection is determined using the time dependent detection function from IMPWAG (Reference 3) with several modifications to fit the structure of the Ground Combat Model.

(b) Visual observation of a target is described by the following three-step process: looking, detecting, and resolving/identifying.

1. Detection is not possible if the amount of light reflected from the target, relative to the background, provides an insufficient stimulus to the eye of a human observer. In this case, when the target's apparent contrast is below some threshold value, an observer could look for an infinitely long time and not detect the target. If the apparent contrast of the target is at or above some threshold value an observer who is looking directly at the target will have some probability of detecting it. An observer who is not looking at the target will have some probability increasing, as a function of time, of eventually looking at it and detecting it.

2. Observation will not occur unless the observer can resolve/identify the target. A target which subtends an angle greater than the minimum angle of resolution can be resolved.

(c) The probability of observation can be expressed by Equation 4-67:

$$P_o = P_{R/D} \cdot P_D = P_{R/D} \cdot P_{D/L} \cdot P_L \qquad (4\text{-}67)$$

where:

P_o = probability of observation

$P_{R/D}$ = probability of resolution given detection

P_D = probability of detection

$P_{D/L}$ = probability of detection given looking at the target

P_L = probability of looking at the target

(d) The probability of resolution given detection, $P_{R/D}$, will be either zero or 1. The value for $P_{R/D}$ is zero if the visual angle subtended by the target is less than the minimum visual angle of resolution, and 1 if the visual angle is greater than the minimum required.

(e) The probability of detection given a look, $P_{D/L}$, is based upon Blackwell's experiments (Reference 4) and Linge's work (Reference 5) that found a relationship between the probability of detection and the targets relative contrast. The relative contrast, C_r, defined by Blackwell is given in Equation 4-68:

$$C_r = \frac{\text{Apparent contrast}}{C_{50}} \qquad (4\text{-}68)$$

where C_{50} is that contrast which has a probability of being detected of 0.50.

1. The probability of detection as a function of C_r is expressed by Equation 4-69:

$$P_{D/L} = \Phi\left(\frac{C_r - 1.0}{.482}\right) \qquad (4\text{-}69)$$

where:

$$\Phi(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x} e^{\frac{-t^2}{2}}\, dt \qquad (4\text{-}70)$$

Equation 4-70 is solved using Hasting's approximation number 43 (Reference 7). Equation 4-69 then takes the form of Equation 4-71:

$$P_{D/L} = 0.5 \pm 0.5\,(1 - Y \cdot \Phi'\,(X)) \qquad (4\text{-}71)$$

where:

$$\Phi'(X) = 1.12838\, e^{\frac{-X^2}{2}}$$

$$Y = 0.308428N - 0.084971\, N^2$$

$$+ 0.6627698\, N^3$$

$$N = \frac{1}{1 + .33267 \cdot |X|}$$

$$X = \frac{C_r - 1.0}{0.482}$$

The $\pm$ in Equation 4-71 takes on the sign of X.

2. Citing the definition of meteorological range from the Glossary of Meteorology (Reference 6) as the range at which a target is barely detectable, C_{50} will be defined as the apparent contrast at the meteorological range of a target having inherent unit contrast, or:

$$C_r = \frac{C_A}{0.02} = 50\, C_A \qquad (4\text{-}72)$$

In order to find C_r for Equation 4-71 it is sufficient to determine C_A, the apparent contrast. The NDRC report (Reference 1) provides Equations 4-73 through 4-75.

The apparent contrast C_A may be written:

$$C_A = \frac{\Delta B_r}{B_r} = \frac{B_r - B'_r}{B_r} \tag{4-73}$$

where:

B_r = target brightness at range r

B'_r = background brightness at range r

$$\Delta B_r = B_o \, e^{-\beta' r} = (B_o - B'_o)\, e^{-\beta' r} \tag{4-74}$$

where:

B_o = target brightness at source

B'_o = background brightness at source

β' = atmospheric attentuation coefficient

r = range from target to observer

$$B_r = B_H (1 - e^{-\beta' r}) + B_o e^{-\beta' r} \tag{4-75}$$

where:

B_H = horizon brightness

The apparent contrast of target j at range r_k may be calculated by substituting Equations 4-74 and 4-75 into Equation 4-73:

$$C_{A_{jk}} = \frac{C_{oj}}{1 + \frac{B_H}{B_o}\left(e^{\beta' r_k} - 1\right)} \qquad (4\text{-}76)$$

The quantity B_H / B_o in Equation 4-76 is the ratio of horizon brightness to background brightness, referred to as the sky-ground ratio. C_{oj}, the intrinsic contrast, is defined by Equation 4-77:

$$C_{oj} = \frac{\rho_j - \rho_B}{\rho_j} \qquad (4\text{-}77)$$

where ρ_j and ρ_B are the reflectances of the target and background. Reflectance is the fraction of incident light reflected. The quantity β' is determined from Equation 4-78:

$$\beta' = \frac{3.912}{R_V} \qquad (4\text{-}78)$$

where R_V is the visible range. Equation 4-78 is the standard definition of β', forcing the visibility to 2 percent at the visible range.

(f) The probability of looking, P_L, is determined by considering the portion of the observer's field of view which is occupied by the target and the observer's capability of resolving a target that is not directly along the direction of a glimpse. In a single glimpse the observer's direction of view will be randomly located within his search angle. The target will also have a random location within the area being searched. The probability that the vectors locating these directions are at an angle between α' and $\alpha' + d\alpha'$ is determined using Figure 4-11. Figure 4-12 is a typical plot of γ versus δ and may be used to extract an estimate of the probability of angular separation between the observer's "looking angle" and the line along which the observer will see the target. The diagonal lines are equations of constant α'; therefore, the probability that the angular separation is between α' and $\alpha' + d\alpha'$ is proportional to the area of the shaded trapezoid. The area of this trapezoid is calculated by Equation 4-79 and approximated by Equation 4-79a:

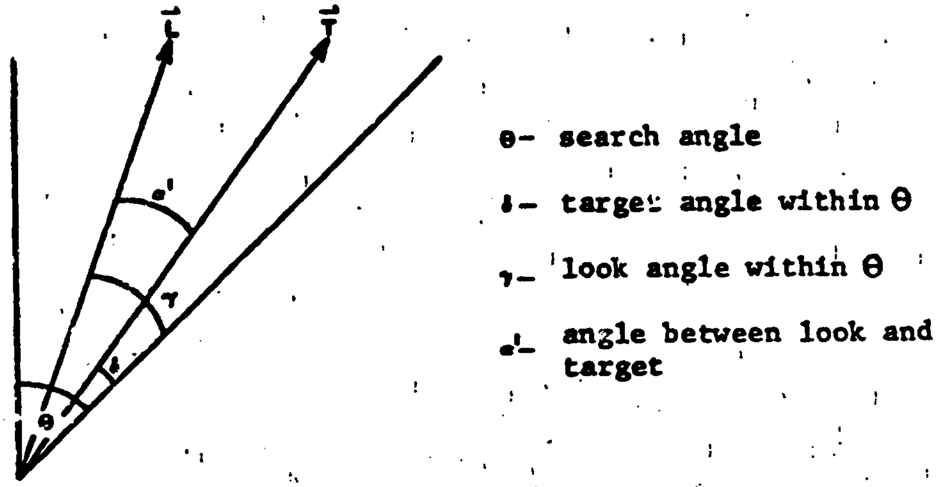


Figure 4-11. Search Vector Geometry

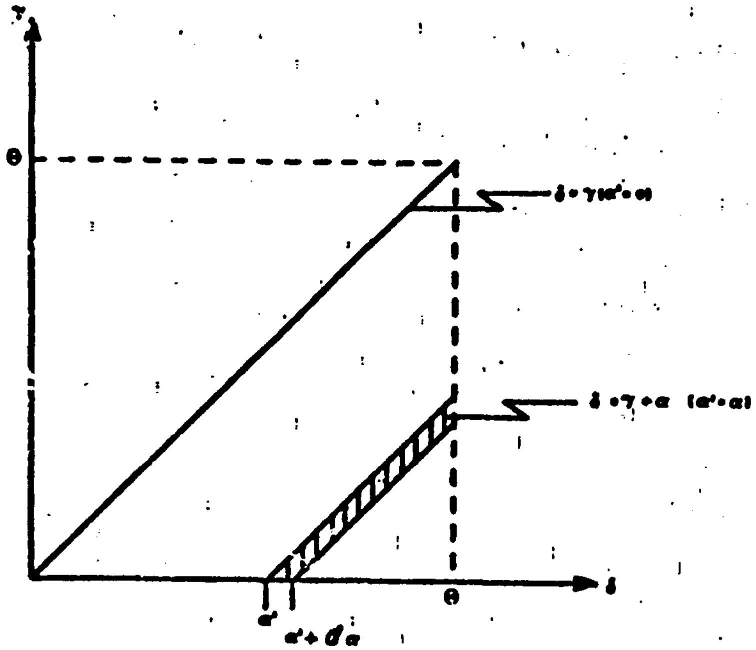


Figure 4-12. Typical Variation of γ versus δ

$$A = 1/2 \left(\frac{\theta - \alpha'}{\cos 45°} + \frac{\theta - (\alpha' + d\alpha')}{\cos 45°} \right) \cos 45° \; d\alpha' \qquad (4\text{-}79)$$

$$\approx (\theta - \alpha') \; d\alpha' \qquad (4\text{-}79a)$$

Hence, the probability of angular separation α is:

$$P(\alpha) \; d\alpha = k(\theta - \alpha) \; d\alpha \qquad (4\text{-}80)$$

where k is the constant of proportionality determined by normalizing Equation 4-80. Evaluating the integral of Equation 4-81:

$$\int_0^{\theta} (\theta - \alpha) \; d\alpha = \frac{\theta^2}{2} \qquad (4\text{-}81)$$

yields the normalization factor $\frac{2}{\theta^2}$. Substituting the normalizing factor into Equation 4-80 yields Equation 4-82:

$$P(\alpha) \; d\alpha = \frac{2(\theta - \alpha)}{\theta^2} \; d\alpha \qquad (4\text{-}82)$$

(g) Visual acuity is used to derive the probability of looking, P_L. This is done by first defining off angle as the angle between the direction of sight and the direction of the target. Visual acuity and off angle, α', are related by Equation 4-83:

$$VA = 2 \frac{1}{1 + 0.643 \, \alpha'} \qquad (4\text{-}83)$$

which is the equation of the curve of Figure 4-13, from References 8 and 9.

1. Visual acuity is commonly expressed as the ratio $\frac{d}{d_N}$ where d_N is the distance at which the normal eye can resolve a given object, and d is the distance at which the specific eye being assigned a visual acuity value can resolve the same target. Since the angle subtended

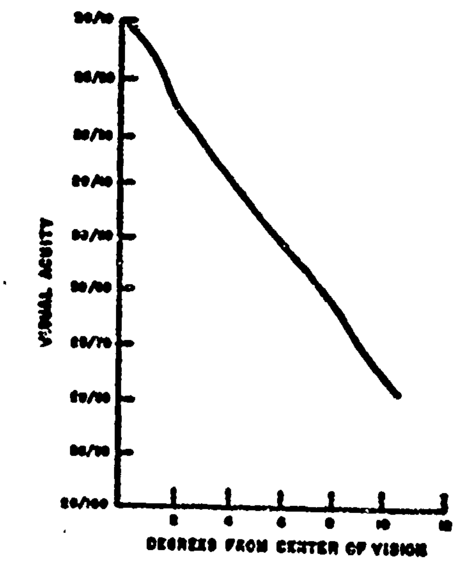


Figure 4-13. Visual Acuity versus Off Angle

by the target is inversely proportional to its distance from the observer, visual acuity can be expressed by Equation 4-84:

$$VA = \frac{d}{d_N} = \frac{\Phi N}{\Phi} \tag{4-84}$$

where:

Φ_N is the angle of subtense necessary for a normal eye to resolve a given object, Φ is the angle of subtense of the specific eye required to resolve the same object.

The minimum visual acuity, (VA)', required to resolve a target subtending an angle β and having minimum angle of resolution θ_1 is obtained from Equation 4-84 by equating Φ_N to $2\theta_1$ and Φ to β.

$$(VA)' = \frac{2\theta_1}{\beta} \tag{4-85}$$

2. The factor of 2 in Equation 4-85 is necessary to convert to the same visual acuity scale used in Ludvigh's work (References 8 and 9), wherein normal visual acuity was assigned a value of 2.

3. Equation 4-83 can be equated to Equation 4-85 and solved for α', yielding Equation 4-86 which defines the maximum off-angle for which resolution is possible.

$$\alpha' = \frac{1}{.643} (\beta / \theta_1 - 1) \tag{4-86}$$

4. Integrating Equation 4-82, and using as an upper limit the value of α' calculated in Equation 4-86, the probability the observer will resolve the target is given by Equation 4-87:

$$P_L = \int_0^{Min(\alpha',\theta)} P(\alpha) d\alpha \tag{4-87}$$

The value Min (α', θ) is used in the upper limit since $P(\alpha') = 0$ for $\alpha' \geq \theta$.

(h) θ_1 is taken to be 47 seconds or 0.000228 radians as the minimum angle of resolution, as suggested by Jenkins and White (Reference 13). β, the angle subtended by a target, is computed using Equation 4-88:

$$\beta = 2 \tan^{-1} \frac{\sqrt{0.02957 \cdot a_{j1}}}{R_k} \tag{4-88}$$

where a_{j1} is the target area (square feet) of target j in posture 1, and R_k is the range to coverage type k. The area of a stationary target is taken to be one-third its exposed value. The factor of 0.02957 enters from the ratio $1 / [(\pi) \cdot (3.28)^2]$ where 3.28 is the conversion from meters to feet. The term $P_{R/D}$ in Equation 4-67 is determined using Equation 4-89:

$$P_{R/D} = \begin{cases} 0, & \beta < \theta_1 \\ 1, & \beta \geq \theta_1 \end{cases} \tag{4-89}$$

Thus, the single glimpse detection probability for unaided visual observers of a single target type j in posture 1 at range R_k can be expressed by Equation 4-90:

$$P'_{jk1} = \frac{1}{\sqrt{2\pi}} \Gamma(\beta, \theta_1) \int_{-\infty}^{W} e^{\frac{-x^2}{2}} dx \cdot 2\int_0^B \frac{\theta - y}{\theta^2} dy \tag{4-90}$$

where:

$$\Gamma(\beta, \theta_1) = \begin{cases} 0, \beta < \theta_1 \\ 1, \beta \geq \theta_1 \end{cases}$$

from Equation 4-89:

$$W = \frac{1}{.482} \left[\frac{50\ (\rho_j - \rho_B)}{\rho_j\ [1 + \frac{B_H}{B_0}(e^{\beta' \cdot R_k} - 1)]} - 1 \right]$$

from Equations 4-72, 4-76, and 4-77; and

$$B = \mathrm{Min} \left[\frac{1}{.643} \left(\frac{\beta}{\theta 1} - 1 \right), \theta \right]$$

from Equations 4-86 and 4-87 and with

β = angle subtended by the target (Equation 4-88)

θ_1 = minimum resolution angle

γ = search angle (taken to be 45°)

ρ_j = target reflectance

ρ_B = background reflectance

B_H/B_0 = sky-ground ratio

β' = atmospheric attenuation coefficient (Equation 4-78)

R_k = range to coverage type k

$\left.\begin{matrix} x \\ y \end{matrix}\right\}$ = dummy integration variables.

(3) Other Sensor Types:

(a) Equation 4-90 gives the detection probability for a single glimpse, taken to require 2.0 seconds according to Paul W. Kruse (Reference 10). For other sensor types the detection probability must be converted to a 2-second time interval before it can be meaningfully combined with the above.

(b) Most existing experimental data provide a detection probability for at least two ranges and a mean time to detect. Let P_1 and

P_2 be the detection probabilities at ranges r_1 and r_2, respectively, and let t_D be the mean time to detect. The detection probabilities per second are determined by Equation 4-92, which assumes detection varies as indicated in Equation 4-91.

$$P(t) = 1 - (1 - P\ (\text{per sec}))^{t} \qquad (4\text{-}91)$$

$$P(\text{per sec}) = 1 - (1 - P(t))^{1/t} \qquad (4\text{-}92)$$

where $P(t)$ is the probability of detection at time t. Substituting P_1, P_2, and t_D into equation 4-92 and converting to the probability per 2 seconds leads to Equations 4-93:

$$P_1\ (2\ \text{sec}) = 1 - (1 - P_1\ (\text{exp}))^{2/t_D} \qquad (4\text{-}93a)$$

$$P_2\ (2\ \text{sec}) = 1 - (1 - P_2\ (\text{exp}))^{2/t_D} \qquad (4\text{-}93b)$$

Assuming the detection probability is exponential in range, as indicated by Equation 4-94, Equations 4-93 and the values of r_1 and r_2 may be substituted to solve for a and b, as indicated in Equations 4-95:

$$P = a\ e^{-br} \qquad (4\text{-}94)$$

$$a = P_1\ (2\ \text{sec})\, e^{\left\{\frac{-r_1\ (\ln P_2\ (2\ \text{sec}) - \ln P_1\ (2\ \text{sec}))}{r_2 - r_1}\right\}} \qquad (4\text{-}95a)$$

$$b = \frac{\ln P_2\ (2\ \text{sec}) - \ln P_1\ (2\ \text{sec})}{r_1 - r_2} \qquad (4\text{-}95b)$$

An a and b are calculated for each sensor type q. Thus, for any sensor type q the 2-second detection probability at range R_k can be calculated using Equation 4-96:

$$P'_{kq} = a_q\ e^{-b_q \cdot R_k} \qquad (4\text{-}96)$$

(c) A check is made on each sensor type to see if it is in use (according to day or night conditions). Observers are assumed to always use unaided visual detection capabilities. The detection probabilities for those

sensors q in use and for unaided vision are multiplied by the line of sight probability of Equation 4-97 to yield P_{jkl} and P_{jklq}:

$$(P_{LOS})_{jkl} = \left\{ 1 + \frac{2 \cdot R_k}{\bar{r}_{jl}} \right\} e^{-(2 \cdot R_k / \bar{r}_{jl})} \qquad (4\text{-}97)$$

$$P_{jkl} = P'_{jkl} \cdot P_{LOS_{jkl}} \qquad (4\text{-}98)$$

$$P_{jklq} = P'_{kq} \cdot P_{LOSjkl} \qquad (4\text{-}99)$$

where P'_{jkl} and P'_{kq} are defined by Equations 4-90 and 4-96.

These results are then combined to yield the probability of detecting at least one target type j in posture l at range R_k using Equation 4-100:

$$PD_{jkl} = 1 - (1 - P_{jkl}) \cdot \prod_q (1 - P_{jklq}) \qquad (4\text{-}100)$$

(4) Correction for Target Density:

(a) Equation 4-100 was derived for a single target in each region. In general, for the detection probability P_N with N targets the resultant probability can be expressed by Equation 4-101:

$$P_N = 1 - (1 - P)^N \qquad (4\text{-}101)$$

If N is noninteger Equation 4-101 can be expressed more generally by Equation 4-102, where P_T is the probability a target is there; i.e., fractional target.

$$P_N = 1 - \prod_{\substack{\text{all} \\ \text{possible} \\ \text{targets}}} (1 - P \cdot P_T) \qquad (4\text{-}102)$$

Substituting Equations 4-66 and 4-100 into Equation 4-102 yields PD'_{jkl}, the probability of detecting at least one of m targets of type j in posture l at range R_k, as indicated in Equation 4-103:

$$PD'_{jkl} = 1 - [1 - PD_{jkl}]^{m_{jkl}(I)} \cdot [1 - m_{jkl}(R) \cdot PD_{jkl}] \qquad (4\text{-}103)$$

where $m_{jkl}(I)$ is the integer part of m_{jkl} and $m_{jkl}(R)$ is the remainder.

(b) The probability of detecting at least one priority target is computed by Equation 4-104:

$$PD = 1 - \prod_{\substack{\text{all}\\ \text{priority}\\ \text{targets } j}} \prod_{k=2}^{4} \prod_{l=1}^{2} (1 - PD'_{jkl})^{k} \qquad (4\text{-}104)$$

The k appears as an exponent since each observer's area contains k sections of coverage type k.

(5) Expected Time to Detect a Target:

(a) PD in Equation 4-104 is the probability of detecting at least one priority target among all targets in both postures throughout the weapon system's area of responsibility in a 2-second time interval. The general expression for the probability resulting from n time intervals is given in Equation 4-105:

$$PD^{(n)} = 1 - (1 - PD)^{n} \qquad (4\text{-}105)$$

The expected value of the number of time intervals required to detect at least one target is given by Equation 4-106:

$$\langle n \rangle = \frac{1}{PD} \qquad (4\text{-}106)$$

and hence the expected time in seconds to detect is given by Equation 4-107:

$$\langle t \rangle' = 2 \cdot \langle n \rangle = \frac{2}{PD} \qquad (4\text{-}107)$$

(b) The time to detect is modified to reflect the possibility that an acquired target is outside the weapon's area of responsibility using Equation 4-108 which assumes the search is uniform throughout the search angle. γ is defined by Equation 4-60 and θ is taken to be 45°.

$$\langle t \rangle = \frac{\gamma}{\theta} \langle t \rangle' \qquad (4\text{-}108)$$

(c) Finally, all detection probabilities are converted to reflect their proper values at time $t = \langle t \rangle$ combining Equations 4-101, 4-103, and 4-106 into Equation 4-109.

$$PD''_{jkl} = 1 - (1 - PD'_{jkl})^{\langle n \rangle} \qquad (4\text{-}109)$$

(6) Pinpoint Probabilities:

(a) The Target Acquisition Submodel calculates independently the pinpoint target acquisition probabilities PP_j from the single round pinpoint probabilities PP'_j and the number of stationary targets j which have recently fired one or two rounds, N_{f1j} and N_{f2j}, that are discussed further in Paragraph 3g, below.

(b) From N_{f1j} and N_{f2j} the number of recent firers in each weapon's area of responsibility is determined using Equations 4-110:

$$n_{f1j} = N_{f1j} \frac{\sum_{k=2}^{4} k \cdot A_k}{A} \qquad (4\text{-}110a)$$

$$n_{f2j} = N_{f2j} \frac{\sum_{k=2}^{4} k \cdot A_k}{A} \qquad (4\text{-}110b)$$

where A was defined in Equation 4-59 and the sum is the total area covered by one weapon. The probability of not pinpointing a target j is calculated by Equation 4-111:

$$\overline{PP}_j = 1 - PP'_j \cdot P_{LOSj22} \qquad (4\text{-}111)$$

where the first subscript 2 represents the median range and the second refers to the stationary posture. Making use of Equation 4-102 the probability of pinpointing at least one target j is given by Equation 4-112:

$$PP_j = 1 - \overline{PP}_j^{\,n_{f1j}(I)} \cdot (1 - n_{f1j}(R) \cdot (1 - \overline{PP}_j))$$

$$\cdot\ \overline{PP}_j^{\,2n_{f2j}(I)} \cdot (1 - n_{f2j}(R) \cdot (1 - PP_j))^2 \qquad (4\text{-}112)$$

where, as before, the I and R refer to the integer and remaining parts of the n's.

e. Firepower Potential Submodel:

(1) General:

(a) The Firepower Potential Submodel uses the target acquisition probabilities generated by the previous submodel and the weapon-target priority assignments to determine the distribution of fires against each target type. Fires are further distributed among the different types of coverage regions and the postures of each target type.

(b) The number of rounds fired by each weapon type is then calculated based upon the expected value of the time to detect at least one priority target, the time to aim and fire the weapon, and the flight time of the round.

(2) Distribution of Fires:

(a) Fires are first allocated among weapon/ammunition combinations linked to the same transport vehicle. If the minimum and maximum range limitations are such that only one weapon/ammunition combination may be applied, that combination is assumed to be used by all vehicles. If the minimum and maximum range limitations of several weapon/ammunition combinations common to a single type transport vehicle are such that more than one combination may be applied, the weapon unit is broken into firing zones as follows. The minimum and maximum depths within the weapon unit in which each weapon/ammunition combination may fire is calculated using Equations 4-113.

$$F_i = \text{Max}\ (0,\ R_{min_i} - S_e - d_T) \qquad (4\text{-}113a)$$

$$B_i = \text{Min}\ (R_{max_i} - S_e,\ 2x) \qquad (4\text{-}113b)$$

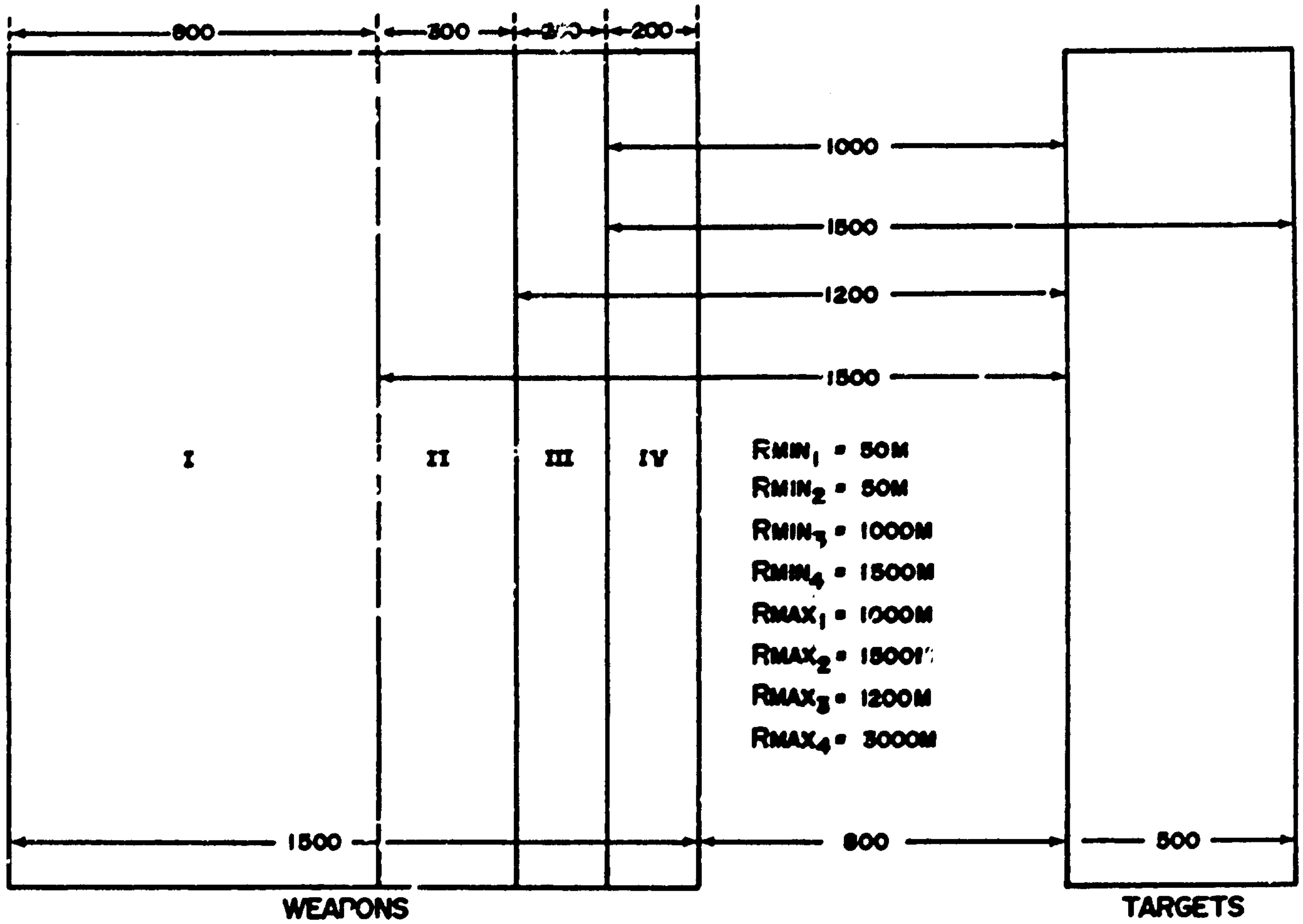


Figure 4-14. Example of Zones Defined by Weapon/Ammunition Range Capabilities

$$P_{j(1)} = 1 - \prod_{\substack{j \\ \text{priority} \\ 1}} \prod_{k=2}^{4} \prod_{l=1}^{2} (1 - PD''_{jkl}) \qquad (4\text{-}117)$$

PD''_{jkl} was defined in Equation 4-109. The probability of acquiring at least one second priority target j and not having acquired a first priority target is calculated in Equation 4-118:

$$P_{j(2)} = \left\{1 - \prod_{\substack{j \\ \text{priority} \\ 2}} \prod_{k=2}^{4} \prod_{l=1}^{2} [1 = PD''_{jkl}] \right\} \cdot (1 - P_{J(1)}) \qquad (4\text{-}118)$$

(c) A calculation is made for the n^{th} priority target using Equation 4-119:

$$P_{j(n)} = \left\{ 1 - \prod_{\substack{j \\ \text{priority} \\ n}} \prod_{k=2}^{4} \prod_{l=1}^{2} [1 - PD''_{jkl}] \right\} \cdot \prod_{q'=1}^{n-1} (1 - P_{j(q')}) \qquad (4\text{-}119)$$

These probabilities represent the fraction of eligible weapons i that will attempt to fire at each target priority class j(n).

(d) Within each target priority class rounds are distributed by range and posture as follows. $P_{j(n)}$ is the fraction of eligible firers that fire at targets type j(n) where n is the priority assignment. The fractions of acquisitions by range and posture are taken to be the simple ratios of Equation 4-120:

$$F_{jkl} = \frac{P''_{jkl}}{\sum_{k=2}^{4} \sum_{l=1}^{2} P''_{jkl}} \qquad (4\text{-}120)$$

(e) $Frac_i$ was determined in Equation 4-116 to be the fraction of weapons of type i in range of some target in the target band; hence, the number of stationary eligible firers of type i is given by Equation 4-121:

$$n_i'' = n_i \cdot Frac_i \cdot (1 - v_w/v_i) \qquad (4\text{-}121)$$

where n_i was defined by Equation 4-28, v_w is the weapon unit velocity, and v_i is the mobility class rate for weapon type i. Thus, the number of firers i firing at each target type by range and posture can be expressed by Equation 4-122:

$$n_{ijkl} = n_i'' \cdot F_{jkl} \cdot \frac{P_j(n)}{\sum_{q'} PD''_{q'kl}} \cdot PD''_{jkl} \qquad (4\text{-}122)$$

where q' is the number of priority n targets.

(3) Number of Rounds Fired:

(a) The number of rounds fired is calculated as follows. One round is fired by each weapon that fires on a stationary target. One round is fired by each weapon that fires on a moving target and maintains line of sight. A second round is fired if line of sight is maintained after the first round. A second round is fired at stationary targets only by a fraction $(1 - PK_{ijk2})$ of the original firers, where PK_{ijk2} is the kill probability for weapon i against a stationary target j at range R_k. PK is discussed further in Paragraph 3f, below. Thus, the number of rounds fired can be expressed by Equations 4-123:

$$RN_{ijkl} = n_{ijkl}[P_{LOS_{jkl}} + P^2_{LOS_{jkl}}] \qquad (4\text{-}123a)$$

$$RN_{ijk2} = n_{ijk2}[\,1 + (1 - PK_{ijk2})] \qquad (4\text{-}123b)$$

(b) Equations 4-123 give the number of rounds fired by time $\langle t \rangle + 2 \cdot T_{iafd}$, where T_{iafd} is the time required for weapon i to aim, fire, and deliver a round. The actual number of rounds fired during an iteration is determined by multiplying Equations 4-123 by the ratio $T / (\langle t \rangle + 2 \cdot T_{iafd})$ where T is the engagement iteration time.

(4) Pinpointed Targets:

(a) Rounds fired at pinpointed targets are calculated independently considering only those eligible weapons not firing at observed targets. The number of weapons is given by Equation 4-124:

$$n_{ipp} = n_i'' - \sum_{n} \sum_{k=2}^{4} \sum_{l=1}^{2} n_{ijkl} \qquad (4\text{-}124)$$

The pinpoint detections are ordered by priorities just as were the observed targets, yielding Equation 4-125, which is analogous to Equation 4-119.

$$P_{j(n)pp} = PP_{j(n)} \cdot \prod_{j(1)} [1 - PP_{j(1)}] \cdots \prod_{j(n-1)} [1 - PP_{j(n-1)}] \qquad (4\text{-}125)$$

(b) Each firing weapon fires only one round, and the number of rounds fired is given by Equation 4-126, which is analogous to Equation 4-122.

$$RN_{ijpp} = n_{ipp} \cdot \frac{P_{j(n)pp}}{\sum_{q'} PP_{q'}} \cdot PP_j \cdot \frac{T}{\langle t \rangle + T_{iafd}} \qquad (4\text{-}126)$$

f. Firepower Effectiveness Submodel:

(1) General:

(a) The Firepower Effectiveness Submodel determines the effect of each type round fired at each target type by interpolating between experimental data points to determine both the probability of a hit and the probability of a kill given a git. The resulting kill probability is applied at the different ranges corresponding to the different coverage regions as well as to the different target postures.

(b) The survival probability for each target type is calculated based upon the total number of rounds entering each coverage region, thereby accounting for the possibility of multiple hits by more than one weapon.

(c) Conditional casualties for each target type are then computed to reflect the range limitations of each opposing weapon type. This is

accomplished by dividing the engaged portion of the target unit into four bands and assessing losses only in those bands within range of the weapon.

(d) These conditional casualties are then distributed among the firing weapons to account for the effect of firing order.

(2) Weapon-Target Kill Probabilities:

(a) The effect of each type round against each target type can be expressed by Equation 4-127:

$$P'_{K_{ijkl}} = P_{K/H_{ijkl}} \cdot P_{H_{ijkl}} \qquad (4\text{-}127)$$

where $P_{K/H_{ijkl}}$ is the probability of a kill given a hit by weapon i on target j in posture l at range R_k, and $P_{H_{ijkl}}$ is the corresponding hit probability.

(b) Experimental hit probabilities for up to six range values for each weapon type are required by a pregame load routine which in turn generates six values of the NATO hit probability (probability of hitting a square target 7-1/2 ft. x 7-1/2 ft.) corresponding to the weapon's minimum range, maximum range, and four intermediate values, all at equal range increments. The Ground Combat Model then performs a linear interpolation on these values to determine the NATO hit probability at any intermediate range. The resulting value is then used to solve for $\sigma^2(r)$ using Equation 4-128:

$$P_{H_{NATO}}(r) = 1 - e^{-R^2/2\sigma^2(r)} \qquad (4\text{-}128a)$$

or:

$$\sigma^2(r) = -R^2/2\ln\left(1 - P_{H_{NATO}}\right) \qquad (4\text{-}128b)$$

where R is the radius of a circular target having an area equal to that of a standard NATO target.

$$R^2 = (7.5)^2/\pi = 17.9\ ft^2 \qquad (4\text{-}129)$$

Equations 4-128b and 4-129 and a radius corresponding to the target's presented area are then substituted into an equation analogous to Equation 4-128a to solve for $P_{H_{ijkl}}$ as indicated in Equation 4-130:

$$P_{H_{ijkl}} = 1 - e^{-(A_{jl}/\Pi) / (17.9)^2 / \ln[1 - P_{H_{NATOik}}]}$$

$$= 1 - (1 - P_{H_{NATOik}})^{A_{jl} / 56.25} \qquad (4\text{-}130)$$

where A_{jl} is the presented area of target j in posture l. One-third the value of the area for fully exposed, moving targets is again used for covered, stationary targets.

(c) The hit probability against a pinpointed target is based upon the experimental results of Project PINPOINT (Reference 11). Citing this reference, a pinpointed target is one which has been located to within $\pm$25 yards of its true location. For ranges less than 500 meters the pinpoint probability was found to be range independent. At these ranges the major error in hitting a target is the horizontal error in location. The Ground Combat Model determines the probability of hitting a pinpointed target by Equation 4-131, where the area of the fully exposed target, in square feet, is used.

$$P_{H_{ijpp}} = \frac{\text{Target width}}{50 \text{ yds.}}$$

$$= \frac{2}{\sqrt{\pi}} \left(\frac{\sqrt{A} \cdot \frac{1}{9} \text{ yds}^2 / \text{ft}^2}{50 \text{ yds}} \right)$$

$$\doteq 0.00752 \sqrt{A} \qquad (4\text{-}131)$$

$P_{K/H_{ijkl}}$ in Equation 4-127 is assumed to be closely approximated by the linear function in range of Equation 4-132:

$$P_{K/H_{ijkl}} = m_{ij} r_k + b_{ij} \qquad (4\text{-}132)$$

where the slope m_{ij} and intercept b_{ij} are determined by a least squares fit to experimental data.

(3) Conditional Casualties:

(a) The number of rounds entering each coverage section directed at target j in posture l is computed using Equation 4-133:

$$TRN_{ijkl} = RN_{ijkl} / (n_i + 1 - k) \qquad (4\text{-}133)$$

RN_{ijkl} and n_i were defined by Equations 4-123 and 4-28, respectively. The factor $(n_i + 1 - k)$ is the number of each type coverage sections.

(b) Conditional casualties, as if this weapon were firing alone and not receiving return fire, are then calculated using Equation 4-134:

$$CK_{ij} = \sum_{k=2}^{4} \sum_{l=1}^{2} (n_i + 1 - k) \cdot m_{jkl} \left\{ 1 - \prod_{\substack{\text{all} \\ \text{possible} \\ \text{rounds}}} (1 - P_{K_{ijkl}}) \right\} \qquad (4\text{-}134)$$

In Equation 4-134, m_{jkl} was defined in Equation 4-66. The term $(n_i + 1 - k)$ is again the number of sections of coverage type k, and $P_{K_{ijkl}}$ is determined from Equation 4-135.

$$P_{K_{ijkl}} = P_{K'_{ijkl}} \cdot P_{F_{jkl}} \qquad (4\text{-}135)$$

$P_{K'_{ijkl}}$ is the probability weapon i kills target j in posture l at range R_k (given that the weapon fires), and $P_{F_{jkl}}$ is the probability the weapon fires. $P_{F_{jkl}}$ is found using Equation 4-136:

$$P_{F_{jkl}} = \frac{1}{I(m_{jkl})} \qquad (4\text{-}136)$$

The functional I is an operator with the following properties: I (integer value) equals integer value; I (noninteger) equals next higher integer.

Substituting Equations 4-135 and 4-136 into Equation 4-134 and again interpreting a fractional round as the probability of a whole round, the conditional casualties are expressed by Equation 4-137:

$$CK''_{ij} = \sum_{k=2}^{4} \sum_{l=1}^{2} (n_i + 1 - k) \cdot m_{jkl}$$

$$\cdot \left\{ 1 - \left(1 - \frac{P'_{K_{ijkl}}}{I[m_{jkl}]} \right)^{TRN_{ijkl}(I)} \left(1 - \frac{TRN_{ijkl}(R) \cdot P'_{K_{ijkl}}}{I[m_{jkl}]} \right) \right\} \qquad (4\text{-}137)$$

I and R refer to the integer part and remainder of TRN_{ijkl}. To Equation 4-137 is added the conditional kills against pinpointed targets, which is determined in an analogous fashion and presented in Equation 4-138:

$$CK'_{ij} = CK''_{ij} + n_i \cdot (n_{f1j} + n_{f2j})$$

$$\left\{ 1 - \left(1 - \frac{P'_{K_{ijpp}}}{I[n_{f1j} + n_{f2j}]} \right)^{TRN_{ijpp}(I)} \right.$$

$$\left. \left(1 - \frac{TRN_{ijpp}(R) \cdot P'_{K_{ijpp}}}{I[n_{f1j} + n_{f2j}]} \right) \right\} \qquad (4\text{-}138)$$

In Equation 4-138, n_{f1j} and n_{f2j}' were defined in Equations 4-110 as the number of firing targets per weapon. PK_{ijpp}' is found by inserting Equation 4-131 into Equation 4-127, and TRN_{ijpp} is calculated in Equation 4-139, where RN_{ijpp} was defined in Equation 4-126.

$$TRN_{ijpp} = RN_{ijpp} / n_i \qquad (4\text{-}139)$$

(4) Weapon Range Limitations:

(a) The conditional casualties given by Equation 4-127 still assume weapon type i acts alone with no return fire. First, the effect of other firing weapon types is considered by determining the survival probability for each target j against all types of incoming rounds. This is accomplished by subdividing the leading band of the target unit into four equal area rectangles with the depth of each equal to one-fourth the total band depth. The survival probability in each subband is then computed considering only those weapons which are capable of firing into each band. The following criteria are used to establish which weapons fire into which bands.

Weapon i fires into	if
None (of the engaged target unit)	$R_{max_i} \leq S_E$
Front 1/4	$0 < R_{max_i} - S_E \leq .375d_t$
Front 2/4	$.375d_t < R_{max_i} - S_E \leq .625d_t$
Front 3/4	$.625d_t < R_{max_i} - S_E \leq .875d_t$
All	$.875d_t < R_{max_i} - S_E$
Back 3/4	$0 < R_{min_i} - S_E - d_w \leq .875d_t$
Back 2/4	$.375d_t < R_{min_i} - S_E - d_w \leq .625d_t$
Back 1/4	$.625d_t < R_{min_i} - S_E - d_w \leq .875d_t$
None	$R_{min_i} - S_E - d_w > .875d_t$

(b) CK_{ij}' from Equation 4-138 is then converted to an average survival probability by Equation 4-140, which is applied to each applicable subband.

$$PS_{ij} = 1 - \frac{CK'_{ij}}{m_j} \qquad (4\text{-}140)$$

The net survival probability of target j in each subband γ is computed using Equation 4-141:

$$PS_{j\gamma} = \prod_{\substack{\text{all } i \\ \text{firing into} \\ \text{band } \gamma}} PS_{ij} \qquad (4\text{-}141)$$

(5) Distribution Among Firing Weapons:

(a) The survival probabilities of Equation 4-141 are first converted to conditional casualties to account for all possible permutations in firing order by utilizing the exponential averaging technique from DIVTAG II (Reference 12). Equation 4-142 results when this technique is applied to Equations 4-140 and 4-141.

$$CK_{ij\gamma} = \frac{(1 - PS_{j\gamma}) \ln (PS_{ij})}{\ln(PS_{j\gamma})} \cdot \frac{m_j}{4} \qquad (4\text{-}142)$$

(b) The total conditional casualties is merely the sum over all subbands of Equation 4-142.

$$CK_{ij} = \sum_{\gamma=1}^{4} CK_{ij\gamma} \qquad (4\text{-}143)$$

The casualties in Equation 4-143 have now been corrected for simultaneously firing weapons, but are still conditional in that the problem of return fire has not been addressed.

g. Assessment Submodel:

(1) General:

(a) The Assessment Submodel first takes the conditional casualties generated by both units and corrects the possibility of return fire among weapon systems and targets. Both losses and expenditures are modified to account for this effect.

(b) A check is made on the remaining time (if any) in the requested engagement duration, and a sensing report is prepared during the appropriate iteration.

(c) The unit history records are updated to reflect the number of weapons that have recently fired either one or two rounds.

(2) Return Fire:

(a) The problem of return fire again makes use of a method from DIVTAG II. First, the individual weapon kills are accumulated to kills by each weapon system using Equation 4-144:

$$\hat{L}_{A_{jk}} = \sum_{i \text{ in } k} CK_{A_{ji}} \qquad (4\text{-}144a)$$

$$\hat{L}_{D_{kj}} = \sum_{i \text{ in } j} CK_{D_{ki}} \qquad (4\text{-}144b)$$

In Equation 4-144a, $CK_{A_{ji}}$ are the conditional kills of attacking target j by defending weapons i. The sum over i is over all weapons i linked to defender weapon system k, and $\hat{L}_{A_{jk}}$ are the total conditional attacking target j losses due to defending weapon system k. Equation 4-144b is a similar description of total defending target k losses due to attacking weapon system j.

(b) The losses calculated in Equations 4-144a and 4-144b are then converted to kill fractions using Equation 4-145:

$$\hat{K}_{A_{jk}} = \frac{\hat{L}_{A_{jk}}}{n_{A_j}} \qquad (4\text{-}145a)$$

$$\hat{K}_{D_{kj}} = \frac{\hat{L}_{D_{kj}}}{n_{D_k}} \qquad (4\text{-}145b)$$

where n_{A_j} and n_{D_k} are the number of attacking weapon systems j and the number of defending weapon systems k; $\hat{K}_{A_{jk}}$ is the conditional fraction of attacking target j killed by defending weapon system k; and $\hat{K}_{D_{kj}}$ is the fraction of defending target k killed by attacking weapon system j. These kill fractions

are then processed through the exponential averaging iteration technique of DIVTAG II that converges to a solution of Equation 4-146:

$$y_j = \frac{\prod_k (1-X_k \cdot \hat{K}_{A_{jk}}) - 1}{\ln[\prod_k (1-X_k \cdot \hat{K}_{A_{jk}})]} \qquad (4\text{-}146a)$$

$$X_j' = \frac{\prod_j (1 - y_j \cdot \hat{K}_{D_{kj}}) - 1}{\ln[\prod_j (1-y_j \cdot \hat{K}_{D_{kj}})]} \qquad (4\text{-}146b)$$

In Equations 4-146a and 4-146b, X_j and y_k are the surviving fractions of attacking weapon systems j and defending weapon systems k, respectively.

(c) The solution of these equations is used to compute losses using Equation 4-147:

$$K'_{A_{jk}} = n_{A_j} \cdot X_k \cdot \hat{K}_{A_{jk}} \qquad (4\text{-}147a)$$

$$K'_{D_{kj}} = n_{D_k} \cdot y_j \cdot \hat{K}_{D_{kj}} \qquad (4\text{-}147b)$$

In Equations 4-147a and 4-147b, $K'_{A_{jk}}$ is the number of attacking target j killed by the surviving fraction of defending weapon system k, with a similar description for $K'_{D_{kj}}$. The kills by weapon types and rounds fired by weapon type are then determined from Equations 4-149, which assume the conversion factor from conditional to real in Equations 4-148 is the same for each weapon that is linked to a specific weapon system.

$$\Delta A_{jk} = \frac{K'_{A_{jk}}}{n_{A_j} \hat{K}_{A_{jk}}} = \frac{K'_{A_{jk}}}{\hat{L}_{A_{jk}}} \tag{4-148a}$$

$$\Delta D_{kj} = \frac{K'_{D_{kj}}}{\hat{L}_{D_{kj}}} \tag{4-148b}$$

$$K_{A_{ji}} = \Delta A_{jk} \cdot CK_{A_{ji}} \tag{4-149a}$$

where $K_{A_{ji}}$ is the number of attacking targets j killed by defending weapon i linked to weapon system k,

$$K_{D_{ki}} = \Delta D_{kj} \cdot CK_{D_{ki}} \tag{4-149b}$$

where $K_{D_{ki}}$ is the number of defending targets k killed by attacking weapon i linked to weapon system j,

$$ARN_{ik} = \Delta A_{jk} \cdot TRN_{ik} \tag{4-149c}$$

where ARN_{ik} is the number of rounds fired at defending target k by attacking weapon i linked to weapon system j,

$$DRN_{ij} = \Delta D_{kj} \cdot TRN_{ij} \tag{4-149d}$$

where DRN_{ij} is the number of rounds fired at attacking target j by defending weapon i linked to weapon system k. In Equations 4-149, TRN_{ij} is determined by summing Equations 4-123 and 4-126 according to Equation 4-150:

$$TRN_{ij} = \sum_{k=2}^{4} \sum_{l=1}^{2} RN_{ijkl} + RN_{ijpp} \tag{4-150}$$

(3) Sensing Report:

(a) A sensing report is prepared for each unit based upon what is seen of the enemy unit at a specific time during the engagement duration. The method of determining the preparation time is described below.

1. If the engagement duration, t_s, is less than 5 minutes and less than the expected value of the time to detect $\langle t \rangle$, as defined in Equation 4-108, a sensing report is prepared at the end of the engagement interval and reported 5 minutes later (i.e., sensing time = t_s, reporting time = t_s + 5 minutes).

2. If the engagement duration is greater than 5 minutes and less than $\langle t \rangle$, all but 5 minutes are allowed for observation (i.e., sensing time = t_s - 5 minutes, reporting time = t_s).

3. If the engagement duration is greater than $\langle t \rangle$, the report is prepared at time $\langle t \rangle$ (i.e., sensing time = $\langle t \rangle$, reporting time = $\langle t \rangle$ + 5 minutes).

(b) The observers will detect only the component of velocity of the enemy unit in the direction of the relative velocity. Recalling the variables u, v, w, z, and v_r from Equations 4-14 and 4-15 the observed defender movement rate is the sum of the products of his velocity components with the relative velocity components, where the relative velocity components are normalized to unity. The rate is expressed in Equation 4-151:

$$v_{D_{est}} = \frac{(w - u) \cdot w + (z - v) \cdot z}{v_r} \qquad (4\text{-}151)$$

Similarly, the estimated movement rate of the attacker is given by Equation 4-152:

$$v_{A_{est}} = \frac{(w - u) \cdot u + (z - v) \cdot v}{v_r} \qquad (4\text{-}152)$$

(c) The observer will detect the center of the engaged portion of the enemy unit as the estimated location. This is depicted in Figure 4-15. From this figure the following relations are observed:

$$XX = \frac{1}{2} \left(\frac{\text{Unit depth}}{\text{Number of bands}} \right) \qquad (4\text{-}153a)$$

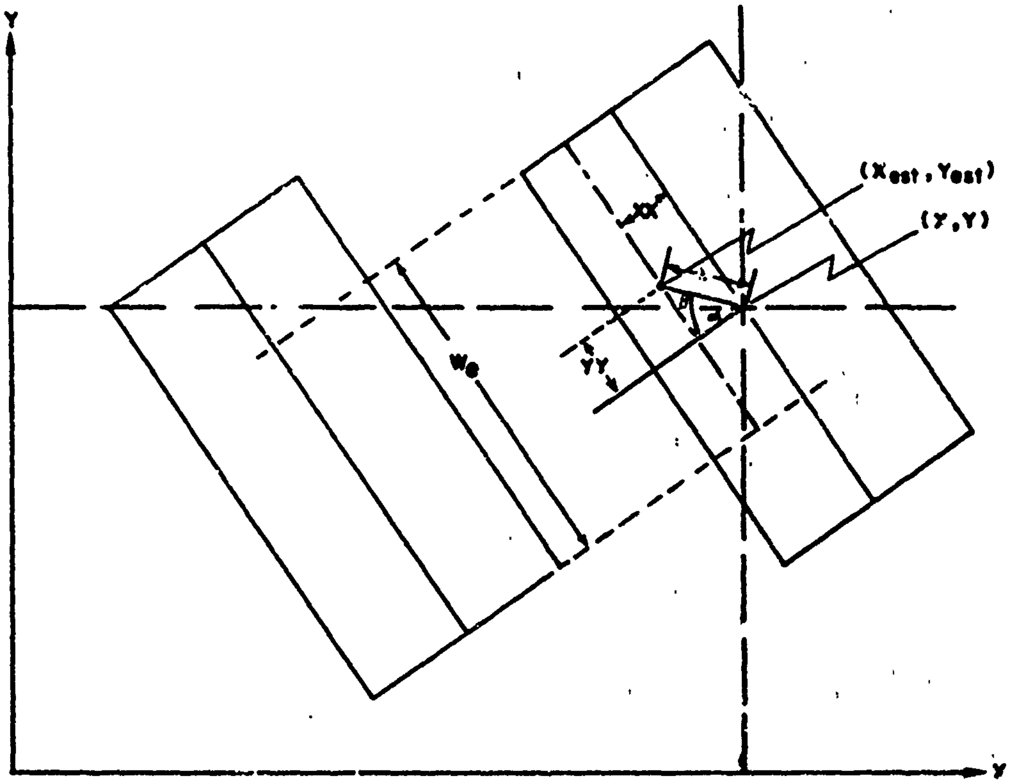


Figure 4-15. Estimated Coordinates

$$YY = \frac{\text{Unit width} - w_e}{2} \tag{4-153b}$$

where w_e was defined by Equation 4-27. The angles α and β are given by Equations 4-154, which make use of Equations 4-153.

$$\alpha = \tan^{-1} \frac{v_{ry}}{v_{rx}} \tag{4-154a}$$

$$\beta = \tan^{-1} \frac{YY}{XX} = \tan^{-1} \frac{(\text{unit width} - w_e) \cdot (\text{number of bands})}{\text{unit depth}} \tag{4-154b}$$

The length λ is given by Equation 4-155:

$$\lambda = \sqrt{XX^2 + YY^2 = \left(\frac{\text{width} - w_e}{2}\right)^2 + \left(\frac{\text{depth}}{2(\text{number of bands})}\right)^2} \tag{4-155}$$

Finally, the estimated locations are related to the location of the unit's center, (s,y), the length 1, and the angle γ defined by Equation 4-156.

$$\gamma = \beta - \alpha \tag{4-156}$$

Examination of Figure 4-15 now shows that the estimated locations can be calculated by Equations 4-157:

$$X_{est} = X + C_1 \lambda \cos\gamma$$

$$Y_{est} = y + C_2 \lambda \sin\gamma \tag{4-157}$$

where C_1 and C_2 are ± 1 depending upon the following conditions:

$$C_1 = \begin{cases} -1, & \text{if } X \geq X_{observer} \\ +1, & \text{otherwise} \end{cases}$$

$$C_2 = \begin{cases} +1, & \text{if } y \geq y_{observer} \\ -1, & \text{otherwise} \end{cases}$$

(d) The estimated direction of movement is the direction of the relative velocity, or α in Equation 4-154a.

(e) The detection probability of Equation 4-109 is applied to the number of targets in each coverage section given by Equation 4-66, according to Equation 4-158:

$$N_{est_j} = \sum_{k=2}^{4} \sum_{l=1}^{2} (n_{fo} + 1-k)\, P''_{jkl}\, m_{jkl} \qquad (4\text{-}158)$$

where n_{fo} is the number of forward observers and where P_{jkl} is evaluated at the time corresponding to the sensing report preparation time. The targets are then identified as tanks, APC's, personnel, or other vehicles and summed over each class. If the estimated number of every class, rounded to the nearest integer, is zero, no report is sent.

(4) Unit History Records:

(a) A part of the unit history update is the determination of each unit's final velocity as a function of the level of activity. Herein it is assumed that those stationary weapon systems which have fired and acquired new targets will remain stationary. Furthermore, those advancing weapon systems which acquire targets will stop. The total number of stationary weapon systems is calculated by Equation 4-159:

$$n_{si} = n_i \left[1- (1-PD^{(n)})(1-PP_j)\right] \qquad (4\text{-}159)$$

where n_i is the number of active weapon systems defined by Equation 4-28, $PD^{(n)}$ is the probability of detecting at least one priority target defined by Equation 4-105, and PP_j is the probability of acquiring a target's signature defined by Equation 4-112. The total number of weapon systems of type i in the engaged portion is given by Equation 4-160:

$$n_{E_i} = f_{i1} \cdot N_i \cdot W_e \,/\, W_w \tag{4-160}$$

where f_{i1} is the fraction of weapon system i in the leading band, N_i is the total number in the unit, and W_e and W_w are the engagement and weapon unit fronts. The fraction stationary can be equated to an expression similar to Equation 4-65 and the result solved for the weapon unit velocity, v_w.

$$v_w = v_i(1 - n_s \,/\, n_{E_i}) \tag{4-161}$$

In Equation 4-161, v_i is the mobility class rate of weapon system i. If v_w is less than the initial weapon unit velocity for any weapon system, the unit is slowed down to the new value.

(b) The number of weapon systems which fire once or twice follows immediately from Equations 4-123 and 4-126:

$$N_{f1_i} = \sum_{k=2}^{4} (n_{ijk1} \cdot P_{LOS_{jk1}} + n_{ijk2}) + RN_{ijpp} \tag{4-162a}$$

$$N_{f2_i} = \sum_{k=2}^{4} [n_{ijk1} \cdot P^{2}_{LOS_{jk1}} + n_{ijk2}(1 - PK_{ijk2})] \tag{4-162b}$$

These values are stored for future use in pinpoint detection probabilities as described for Equations 4-110.

(5) Scheduling Mortar Fires. The firing of area fire weapons (mortars) organic to units involved in ground combat is scheduled within the GCM. Assessment of results of these fires is accomplished by the Area Fire Model.

(a) Decision to Fire. A decision to schedule mortar fires is made if a unit has detected, according to GCM acquisition routines, any personnel targets in an opposing unit. The determination of whether to schedule mortar fires is made for every opposing pair of units at the end of each GCM assessment increment. Thus, should a unit be opposing more than one enemy unit within the GCM, an independent decision to fire is made; and the calculations presented below are made independently for each opponent. Given the acquisition of personnel targets at some time within a GCM increment, the time of first acquisition, t_a, is set by drawing a random number between the beginning time and ending time of the GCM increment.

(b) Unit Locations. To schedule an Area Fire assessment, the location of the target unit and the firing unit must be provided to the Area Fire Model. These are developed as follows:

1. Location of Target Unit. The target acquisition routines of the GCM develop a sensing report which includes estimated location, speed (if moving), and direction of movement (if moving) of the opposing unit at the end of the GCM increment. These items, plus the time of first acquisition, t_a, are used to develop an estimated target location at time of first acquisition. If the target unit is not moving, then the estimated coordinates (x_e, y_e) are used as the target coordinates (x_t, y_t). If the target is moving, coordinates are calculated by projecting back, in time, to the time of first acquisition.

$$x_t = x_e + v_e \cdot \Delta t \cdot \cos\beta \qquad (4\text{-}163a)$$

$$y_t = y_e + v_e \cdot \Delta t \cdot \sin\beta \qquad (4\text{-}163b)$$

where:

x_t, y_t = target coordinates for mortar firing

x_e, y_e = estimated target coordinates at end of GCM increment

v_e = estimated target unit velocity

Δt = time at end of GCM increment minus time of first acquisition.

2. Location of Firing Mortars. The mortars are simulated as firing from that point where the rear edge of the front band of the firing unit is intercepted by a perpendicular constructed from the target location to the rear edge of the firing unit's front band. If the firing unit was moving during the GCM increment, the location of the front band is projected back in time to its location at the time of first acquisition.

3. Discussion. The above calculations determine the estimated location of the target and a location for mortars at the simulated time of first acquisition. These are the firing and designated target coordinates provided to the Area Fire Model for assessment of mortar effects. The target location will generally be at the approximate center of that portion of the front band of the target unit used for GCM assessments. The firing location is generally at the lateral midpoint and rear edge of that portion of the firing unit's front band used for GCM assessment. Prior to further mortar scheduling, a check is made on the range from the firing point to the designated target point. If this range is greater than maximum effective range or less than minimum range of the mortar, firing will not be scheduled.

(c) Volume of Fire. The volume of fire scheduled depends on number of mortars available to fire, number of rounds available, firing rate of the mortar and duration of simulated firing. If the firing unit has more than one type mortar, calculations are conducted independently for each type.

1. Available Mortars and Rounds. The number of mortars available to fire on this target and maximum rounds available for this type mortar are computed as:

$$m_j = m_u \cdot F/W_u \quad (4\text{-}164a)$$

$$r_j = r_u \cdot F/W_u \quad (4\text{-}164b)$$

where:

m_j, r_j = number of mortars and rounds available to fire on this target

m_u, r_u = number of mortars and rounds actually within the firing unit

F = GCM engagement frontage for this pair of units

W_u = total frontage of the firing unit.

2. Rounds Fired per Mortar. The number of rounds fired per available mortar is calculated as:

$$rpm = (t_i - t_a - t_d)/rof$$

where:

rpm = number of rounds to be fired per mortar

rof = rate of fire of mortar (seconds per round), sustained

t_i = time of end of GCM increment

t_a = time of first acquisition

t_d = time to fire first round.

Thus, each available mortar is simulated to fire at its sustained rate of fire from the time of first acquisition, plus the delay time to fire the first round, up to the end of the GCM increment.

3. Total Rounds Fired. The total number of rounds to be fired is set as the minimum of the rounds available to fire on this target (r_j) and the number of mortars available times rounds fired per mortar ($m_j \cdot rpm$); that is, the number of rounds fired by this type mortar, rnds, is:

$$\text{rnds} = \min(r_j, m_j \cdot \text{rpm}) \tag{4-165}$$

(d) Interface and Scheduling. This portion of the GCM interfaces directly with the Area Fire Model both in its use of the Area Fire Model data base to find the necessary parameters of any area fire weapons organic to the units involved in ground combat and in its scheduling of Area Fire assessment. The Area Fire assessment is scheduled by the GCM to take place immediately after the GCM assessment. The Area Fire Model is then called by the event sequencing logic of the DIVWAG Model and carries out the assessment as it would any area fire event.

h. Ground Combat Model Driver (Termination Phase):

(1) The Ground Combat Model driver is not entered until the entire scheduled engagement duration between the initial unit-pair has been completed. The driver continues to process all other unit-pair combinations on the list of surface units associated with the battle.

(2) After all the pairs have been treated the Unit Status File for each participating unit is updated to reflect new coordinates, velocity, losses, expenditures, and consumption. All history records are stored for future use. The sensing report is scheduled to enter the Intelligence and Control Model. If the current loss rates predict more than 10 percent loss to any equipment item in a subsequent 15-minute engagement duration, a shorter engagement time is provided GCMDT for scheduling future engagements so that the 10 percent loss will not be exceeded.

4. REFERENCES:

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CHAPTER 5

AREA FIRE/TACFIRE MODEL

1. MILITARY ACTIVITY REPRESENTED. The Area Fire/TACFIRE Model represents the scheduling, delivery, and assessment of nonnuclear area fire munitions by cannon systems, missile systems, and multiple rocket launchers, and the assessment of mortar fires generated by the Ground Combat Model. The aspects modeled include the fire planning, target analysis, fire direction, and fire support coordination functions inherent in the employment of field artillery as well as the assessment of target damage resulting from the execution of the scheduled fire missions. The tactical fire direction and coordination capabilities of the division TACFIRE system are also represented within the model.

2. MODEL DESIGN:

a. Submodels of the Area Fire/TACFIRE Model. The Area Fire/TACFIRE Model consists of three submodels designed to represent the employment of area fire conventional field artillery systems. These submodels are the DSL FIRE Order Scheduling Submodel, the division's TACFIRE Scheduling Submodel, and the Delivery and Assessment Submodel. A macroflow of the relations among these submodels and between these submodels and other models and/or external DSL gamer control is shown in Figure 5-1. The individual submodel structures are discussed in detail in Paragraph 3.

b. Fire Units in the Area Fire/TACFIRE Model. Fire units used in the model may be at a battalion or at a battery level of resolution, at the user's discretion. Each fire unit may contain up to four area fire weapon/ammunition combinations, although only one combination can be used for one fire mission. TACFIRE controlled missions are fired as full unit volleys. The number of rounds or rockets fired per volley is equal to the number of integral tubes or launchers. In the TACFIRE mode each division is allowed a maximum of 36 fire units. No limit is set on the number used in the DSL mode. For each weapon system defined there is also defined a corresponding munition load representative of the munitions delivered by the weapon system. In the case of a multiple rocket launcher weapon system firing multiple rounds in a small time interval, the "equivalent round" is the total number of rounds fired during the interval. Elements such as lethal areas, weights, and firing times, and all bookkeeping in the model, are represented in terms of this equivalent round.

c. DSL Planned Fires. The model's representation of planned fires on areas or points is accomplished in response to DSL FIRE orders. These fires are planned prior to each game period and correspond to scheduled fires delivered at specific times during the operation of the supported forces. The DSL ordered fires take priority over any fires developed within the "automatic" or TACFIRE mode of the model. With the DSL FIRE order the gamer can specify the number of rounds or volleys and the munition type to be used.

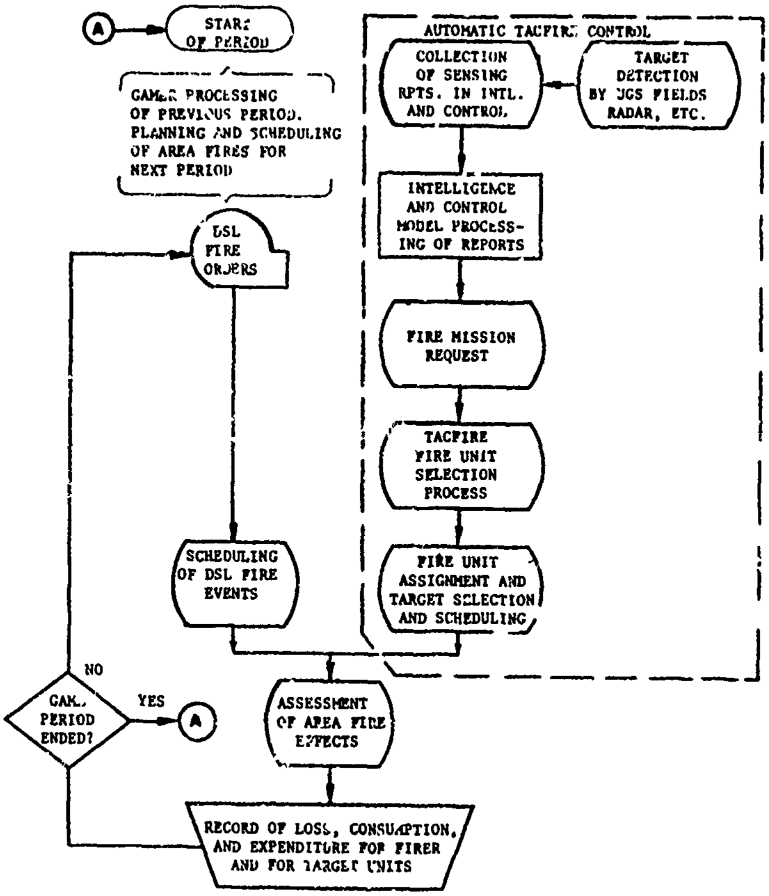


Figure 5-1. DIVWAG Area Fire/TACFIRE Model Macroflow

The locations specified for the fire are derived from the previous period's output intelligence report and the gamer's coordination of fire support with the plan of operation for the next period.

d. TACFIRE Scheduled Fires. Fire missions against targets of opportunity are represented in the TACFIRE system submodel. These targets represent targets that have not been previously considered, analyzed, or planned, and usually are expected to be fleeting in nature. The TACFIRE Scheduling Submodel in the Area Fire/TACFIRE Model is patterned after the division TACFIRE system and is based on reference material obtained from the Functional System Design Requirements Study for TACFIRE (Reference 1). Fire mission requests are generated in the intelligence and Control Model after the targets have been detected and a target analysis performed. Details of this process are specified in the Intelligence and Control Model discussion in Chapter 3. All fire units within a division that are given either STAY orders or no order at all are available for assignment by the TACFIRE submodel routines.

(1) Specific Target Types. Specific fire missions considered in the TACFIRE Model include counterbattery fires, supporting fires fired at the request of maneuver units engaged in ground combat, and fire missions fired at targets detected by UGS fields and radar detection systems and reconnaissance missions. The targets developed in the Ground Combat Model correspond to direct support (DS) requests. Within the model a maximum of two DS fire units is allowed for each maneuver brigade/regiment. Identification of DS requests and fire unit selection are discussed in the submodel specifications.

(2) Forces Without TACFIRE. Each division has a TACFIRE system capability within the model. To represent divisions without such a capability, the model input parameters representing the response time required to fire the initial volley of a fire mission for each type of fire unit can be increased to allow for lack of coordination and for slower tactical and technical fire direction procedures. This assumption has been used in the TACFIRE Cost Effectiveness Study (Reference 2).

(3) TACFIRE Target Priorities and Fire Unit Selection Control. To model the fire unit selection process and the selection of targets from a priority list, the TACFIRE Model requires, as input data, target priority tables and method of attack tables.

(a) Target Priority Tables. The target priority tables represent the division commander's priority considerations for selecting targets and assignment of fire missions. The priority scale is limited to integer values between one and four, with priority one having the highest priority. The four target priorities based on their relative military worth as defined in FM 6-20 and used in studies such as Legal Mix III(Reference 8, can be used. If added resolution of target priorities is required, a larger number of priority categories could be implemented. These target priorities, regardless of the categories used, are based on considerations of the target analysis estimated parameters: size, activity, type, and proximity to maneuver units.

These parameters are fully described in the submodel specifications of the subroutine AFTFC1. Although the priority assigned to a target is a division priority, it will not restrict a brigade commander from using his DS fire units on what may be lower priority targets.

(b) Method of Attack Tables. The method of attack tables provide the model with input data describing the choice of weapon systems in order of preference for employment against a target and the level of attack to use against the target. No massing of fire units is allowed, but the number of volleys desired from a single fire unit against a given target is specified as input data in the method of attack table. A detailed description of the attack tables and their use in the fire unit selection process is given in the submodel specifications section.

(c) Fire Direction Control Arrays. The TACFIRE Model routines maintain a complete record of the status of each fire unit in the division. This fire unit status record, together with division target list information, is used to select fire units for fire missions in accordance with the target priority assignments and method of attack information provided as indirect gamer model control data. Thus, each division has a tactical fire direction center simulated within the model structure.

e. Scheduling of Volleys. The scheduling of fire events within the model occurs for each volley fired in every fire mission. The time lapse between the target entering the TACFIRE system and the first volley fire event of the fire mission is the total response time expected for a typical fire unit composed of the particular weapon system type selected for the mission, and includes an average TACFIRE capability response time, technical fire direction response time, and average time of flight of the rounds. The scheduled time of the fire event is the impact of the volley within the target area. The parameters used in time sequencing the volleys are the weapon firing rates provided in the input data. Identical time parameters are used to schedule the volleys, regardless of whether the fire mission is in respone to a DSL FIRE order or a TACFIRE request. All assessment events occur immediately following the impact events.

f. Assessment Effects. The modeling of the effects of area fire munitions is performed in the Delivery and Assessment Submodel. The submodel is also responsible for identifying all units and individual sensors within the effects area of the munitions.

(1) Target Geometry. Target assessment is based on the expected coverage by each volley of the bands of a rectangular target unit. The geometry of all units is rectangular with up to four variable-density, equal-area bands per unit. This representation of each unit is set dynamically within the DIVWAG system and is based on the unit's movement and present activity. Unit geometry is discussed in detail in the submodel specifications.

(2) Target Location Errors. The actual aim points for fire missions are provided by the Intelligence and Control Model after including target location errors. The systematic errors for each volley are assumed to be zero for purposes of computing the assessment effects of the rounds in the coverage problem.

(3) Equipment Losses. Computation of equipment losses is achieved in two steps. The primary equipment items are assessed using a modification of the DIVTAG II assessment equation (Reference 4). The lethal areas of the round or equivalent round against primary equipment items are specified as input data. The loss of secondary equipment contained on or in primary items is accounted for by using the secondary loss tables. Fractional losses are carried for all items and are rounded only for periodic output summary reports.

(4) Casualty Assessments. Casualty assessments are determined by a dynamic assignment of the present personnel strength of a unit to various protection categories afforded by equipment types present in the unit and consistent with the activity of a unit. Personnel not afforded equipment protection are distributed in standing, prone, or foxhole postures and in warned and unwarned states. Personnel protected by primary equipment items are assessed if losses occur, and unprotected personnel are assessed using lethal area values specified in the input data. Details are given in the specifications of the assessment submodel.

g. Suppression Effects. Units that are executing MOVE or FIRE orders in the model are expected to show suppressive effects from the incoming rounds in addition to the casualties and equipment loss sustained. Units which suffer personnel casualties are suppressed. For units that are moving, the suppression is represented by halting the unit for a short period and thus temporarily limiting the unit's mobility. For firing artillery units, the suppression is represented by an increase in the response times and the times between volleys in the current fire mission of the fire unit being assessed. If a fire unit is currently suppressed, then the TACFIRE Model selection routines will not consider the unit a viable candidate for assignment of a subsequent fire mission. The suppressed fire unit becomes available upon completion of the suppression delay time imposed.

h. Area Fire/TACFIRE Model Interaction with Other Models. The Area Fire/TACFIRE Model interacts or is constrained by the Ground Combat Model, the Intelligence and Control Model, the Combat Service Support Model, and the Movement Model.

(1) Ground Combat Model Interactions. The interaction with the Ground Combat Model is derived through ground combat sensing reports processed by the Intelligence and Control Model, which lead to requests for DS fire missions. The assessment portion also performs the assessment of damage due to mortar fire generated in the Ground Combat Model.

(2) Intelligence and Control Model Interactions. The interactions of the Area Fire/TACFIRE Model with the Intelligence and Control Model occur through the fire mission requests sent to the Area Fire/TACFIRE Model's TACFIRE submodel. The interface between the two models is achieved in the division target list.

(3) Combat Service Support Model Interactions. The Combat Service Support Model affects the Area Fire/TACFIRE Model's TACFIRE section by altering the fire unit selection process through resupply of munitions in fire units. The range-munitions factor providing the interaction is discussed in the submodel specifications of AFTFC1.

(4) Movement Model Interactions. Fire units are constrained by the Movement Model by not allowing moving fire units to fire; i.e., no echelon movement is modeled. Detection of moving targets is also dependent upon movement rates supplied by the Movement Model.

(5) Environment Interactions. The Area Fire/TACFIRE Model's only interaction with the environment is in the assessment of casualties. The lethal areas specified in the input data include forest and unforested values and are used in the model depending on the current terrain cell forest condition in which the target unit is located.

3. SUBMODEL SPECIFICATIONS. The submodels of the Area Fire/TACFIRE Model are represented in the period processor of the DIVWAG system by the subroutines FIREDT, AFTFC1, AFTFC2, and AREAFIRE. The technical aspects of each of these subroutines as they relate to the planning, allocation, and scheduling of artillery fire support and the delivery and assessment of fires are described in the following subparagraphs. The DSL Fire Scheduling Submodel and the division TACFIRE Scheduling Submodel perform the planning, allocation, and scheduling of artillery fire support. The Delivery and Assessment Submodel performs the delivery and assessment of fires.

a. DSL Fire Scheduling Submodel. All planning, allocation, and scheduling of DSL fire missions is performed in the gamer input phase.

(1) DSL FIRE Orders. DSL fire missions are input in DSL FIRE orders. A typical DSL FIRE order has the following form:

```
ID: R12141MB
    STAY FOR 30 MINUTES
    FIRE MUNITION TYPE A001 ON 0141000-011300
    IMPACT RADIUS 100 NUMBER OF VOLLEYS 3.
```

The munition type, A001, identifies the munition as a conventional area fire munition by the letter A. The particular weapon system and munition type is identified by the last two digits (01) and corresponds to the weapon/munition combination index (01) specified in the pregame preparation of the weapon munitions characteristics table. The fire unit specified is identified

initially in the DSL order string (i.e., R12141MB in the example). The aim point for the volleys is contained in the easting-northing coordinates specified in meters from the model's map grid origin (e.g., 0141000-011300). The impact radius specified is not used by the model. Instead a maximum search radius specified in the pregame data in the weapon munitions characteristics table is used to determine if units are within the effects area of the rounds or volley. The number of volleys or number of rounds in the fire mission must also be specified in the fire order. (In the example three volleys are indicated.) The number of rounds in each volley is always equal to the current number of weapon systems on hand in the fire unit.

(2) DSL Fire Mission Priority. DSL fire missions have priority over area fires developed in the TACFIRE submodels. They are always executed if the fire unit's weapon systems are intact and munition is available. Fire units are withdrawn from the TACFIRE mode for the length of time necessary to complete the DSL fire mission. They are returned to the TACFIRE mode if they receive no subsequent DSL order or receive a DSL STAY order.

(3) Fire Mission Volleys. The volleys of the fire mission are scheduled individually and are subject to checks on the fire unit's weapon system strength and munitions supply prior to each volley. The starting time of the fire mission is usually specified by giving the fire unit a STAY order until the time at which the fire mission is to be executed. When the game time reaches the end time of the STAY order the pending FIRE order is processed by the DIVWAG System Event Sequencing Routine, and subroutine FIREDT is called to schedule the impact time of the first volley. A simplified macroflow of FIREDT is shown in Figure 5-2.

(a) The time to fire the initial volley is obtained from the weapon/munitions characteristics data, Figure 5-3, for the weapon/munition combination specified in the FIRE order. This time is used to schedule the subsequent delivery and assessment event within the Delivery and Assessment Submodel.

(b) As soon as the assessment event has been completed, the next volley is scheduled using the time between rounds data. The second through nth volleys are scheduled at the maximum firing rate of the weapon system. After the nth volley (nth round cutoff data) the sustained firing rate of the system is used to schedule subsequent volleys.

(4) Munition Expenditure. Update of the fire unit's status for munitions expenditure is accomplished within the Delivery and Assessment Submodel following each volley.

(5) Target Location Errors. All target location errors in DSL-ordered fire are gamer input. Thus, the estimated target locations must be realistically based on intelligence data supplied in end of period reports to accurately reflect actual situations.

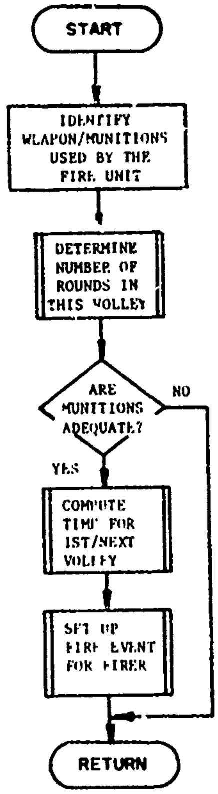


Figure 5-2. FIREDT Macroflow

Characteristic	Value		
Weapon/munitions combination index	1	2	3....
Weapon item code index	29	29	
Munitions item code index	30	31	
Maximum range of combination (meters) R_{mx}	26,500	26,500	
Minimum range of combination (meters) R_{mn}	2,500	2,500	
Time to fire initial FFE volley (seconds)	90	90	
Time between volleys 1-N (seconds)	15	15	
Time between volleys at sustained rate (seconds)	60	60	
Nth round cutoff	30	30	
Munition precision error of round at R_{mx} (CEP)	383	383	
Munition precision error of round at $0.8(R_{mx}-R_{mn}) + R_{mn}$	237	237	
Munition precision error of round at $0.6(R_{mx}-R_{mn}) + R_{mn}$	165	165	
Munition precision error of round at $0.4(R_{mx}-R_{mn}) + R_{mn}$	88	88	
Munition precision error of round at $0.2(R_{mx}-R_{mn}) + R_{mn}$	59	59	
Munition precision error of round at R_{mn}	35	35	
Radius of effects of battalion volley	200	200	

Figure 5-3. Weapon Munitions Characteristics Table

(6) Range Constraints. The range limitations of the weapon systems of the fire units are checked in the Delivery and Assessment Submodel; and, if the designated coordinates of the fire request are not within the range limits of the weapon system, the volley is not fired.

b. Division TACFIRE Scheduling Submodels. Automatic model planning, allocation, and scheduling of fire missions against targets of opportunity during dynamic game periods are performed by the combined interactions of the Intelligence and Control Model and the Area Fire/TACFIRE Model subroutine AFTFC1.

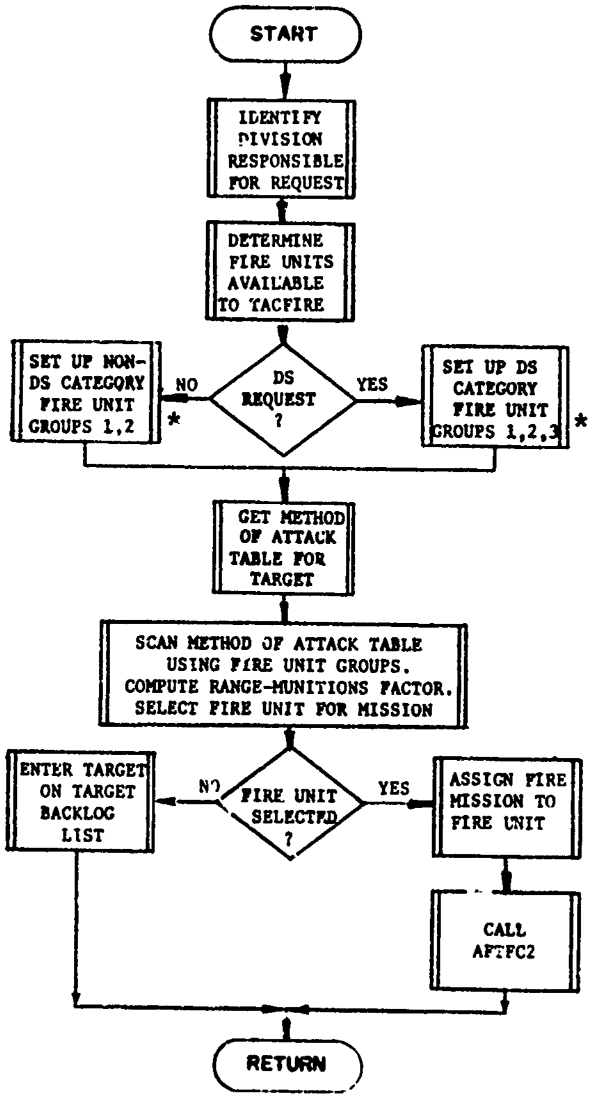
(1) Area Fire Tactical Fire Control, Section 1 (AFTFC1). This subroutine receives fire mission requests from the Intelligence and Control Model, selects fire units, and assigns fire missions to these fire units. A macroflow of the subroutine is illustrated in Figure 5-4.

(a) TACFIRE Fire Mission Requests. The Intelligence and Control Model sends fire mission requests to AFTFC1. The fire mission requests contain the following target intelligence information and model processing information:

. Identity of the unit detecting the target
. Identity of the unit requesting the fire mission
. Sensing report number
. Identification of the target unit
. Estimated target type
. Estimated target size
. Estimated target activity
. Estimated rate of movement
. Estimated direction of movement
. Time the target was last detected
. Identification of redundant fire mission requests

The target estimated type is identified as one of the following.

. 1 - Infantry
. 2 - Armor
. 3 - Mechanized infantry
. 4 - Reinforced task force
. 5 - Tube artillery
. 6 - Missile artillery
. 7 - ADA guns
. 8 - ADA missiles
. 9 - Air base
. 10 - Engineer
. 11 - Command post



*See definition, paragraph 3b(1)(d)1b, page 5-14.

Figure 5-4. AFTF 1 Macroflow

Estimated target activity is specified as:

- 1 - Inactive
- 2 - Move
- 3 - Fire
- 4 - Engineer
- 5 - Attack
- 6 - Defend
- 7 - Withdraw

Estimated target size categories are specified as:

- 1 - Platoon-size target
- 2 - Company-size target
- 3 - Battalion-size target
- 4 - Greater than battalion-size target

(b) Division Target List Information. The target information received in the fire mission request is stored on the division's target list. The target list contains all the fire mission requests pending within the division's zone of responsibility. Information stored on the target list includes the following:

- Record number of target unit on Unit Status File (USF)
- Latest sensing report number
- Estimated x-coordinate
- Estimated y-coordinate
- Estimated rate of movement
- Estimated direction of movement
- Time of last detection
- Combined target activity, size, type index
- Identification of echelon of unit requesting the fire mission
- Identification of unit requesting the fire mission
- USF record number of DS units if this is a direct support request
- USF record number of the nearest friendly maneuver unit
- Target priority
- Time when fire mission was received in AFTFC1.

Each divisional center is allowed a maximum of 48 pending fire mission requests. If an additional request is received when the list is full, the target with the lowest priority is dropped from the list and the new one is added.

1. Stationary targets remain on the target list until the fire mission request has been completed or until an updated fire mission request supersedes the previous target intelligence. The updated information is retained, and the old target information is deleted.

2. Moving targets are subject to the same conditions as stationary ones with the exception of a time limit that is imposed on the target's time on the target list. If the target is estimated to have moved at least 3000 meters based on the latest estimated rate and time of last detection, it is dropped from the target list.

3. Every target received by AFTFC1 is assigned a target priority based on the target's estimated type, size, activity, and proximity of the target to the nearest friendly maneuver unit. For each combination of target type and activity, three range categories are defined, and priorities within these range categories are established as part of the data preparation phase. The priority value scale can range from one to four, with only integer values allowed and one denoting the highest possible priority. The submodel identifies the range category by locating the front line maneuver unit that is closest to the target. The separation between the maneuver unit and the target is used to determine the range category.

(c) Division TACFIRE Fire Unit Status Record. The status of each fire unit within a division's TACFIRE system is maintained on the Division Fire Unit Status Record (FUSRCD). Information maintained includes the following:

- USF record number of fire unit
- Fire unit mission code (DS=1, REINF=2, GS/REINF=3, GS=4)
- Fire unit pending order code
- Weapon equipment item code
- Maximum range of weapon
- Minimum range of weapon
- Weapon/munition combination index (for each munition)
- ASR priority cutoff (for each munition)
- ASR (for each munition)
- Fire unit's mission assignment code
- Number of volleys assigned in present fire mission
- Number of volleys fired in present fire mission
- Number of rounds in each volley of current fire mission
- Weapon/munitions combination used in fire mission
- Scheduled end time of present fire mission
- Target aim point (x, y) coordinates

(d) Fire Unit Selection Process Logic. The selection of a fire unit to execute a fire mission request is determined by combining several selection criteria to represent current availability of fire units, on-hand supply of munitions for candidate fire units, organizational mission responsibilities of fire units (i.e., GS, GS/REINF, REINF, and DS), range to target, and weapon/munitions effectiveness. This information is combined by the logic in AFTFC1. The selection process used is representative of situations where a new target has been received in the system and several fire units are available for the possible assignment to the mission.

1. The available fire units initially listed are those fire units that are: (1) in the TACFIRE mode, (2) within maximum and minimum range limits of the target, and (3) currently not assigned a fire mission. This set of available fire units is further subdivided into "priority of selection" groups dependent upon the fire mission request categories recognized by the model. These fire mission request categories are either DS fire mission requests (DS category) or other fire mission requests (non-DS category).

a. Fire missions categorized as DS requests are identified as all fire mission requests originating in maneuver battalions or brigades/regiments. For each DS request, the DS artillery fire unit(s) assigned to the maneuver brigade/regiment are identified and stored. All other fire mission requests belong to the non-DS category.

b. In the selection process for the DS category, all available fire units are grouped in order of possible consideration for fire mission as follows:

- Group 1 - Unit or units in DS of battalion or brigade/regiment requesting fire mission
- Group 2 - All available GS, GS/REINF, REINF units
- Group 3 - All other available DS units, where availability is defined as before.

c. The grouping for the non-DS category in order of possible consideration for fire missions is as follows:

- Group 1 - All available GS, GS/REINF, and REINF units
- Group 2 - All available DS units.

2. Before the selection process can begin, the weapon/munition effectiveness and/or choice of weapon preference must be specified. These items are supplied in the pre-game data preparation of the method of attack tables. Each specific target combination considered has a method of attack table specifying the weapon/munitions combinations, in order of preference, and the level of attack. A typical method of attack table is shown in Figure 5-5.

a. Within the method of attack table the weapon/munition combinations for potential employment against the target are listed in order of preference. This preference should be based on the effectiveness of the systems as derived in studies such as Legal Mix IV (Reference 3), TACFIRE Requirements Study (Reference 1), FM 6-141-1 (Reference 5), Munition-Target Relationships Study (Reference 6), and on the particular scenario or doctrinal concepts applicable to the particular game situations being considered.

TARGET INTELLIGENCE INFORMATION:

Estimated type (2) ARMOR

Estimated activity (2) MOVE

Estimated size (5) BATTALION

Method of Attack	Weapon/Munition Preference 1	2	3	4	5	6	7	8	9
Weapon/munitions combination index	11	10	9	3	7	6	5	4	8
Weapon index	92	48	20	46	83	90	83	42	85
Munitions index	93	51	22	47	84	91	84	43	86
Level of attack, number of fire unit volleys	1	1	2	4	8	8	8	8	5

Figure 5-5. Method of Attack Table

b. The level of attack is the number of full fire unit volleys required in the fire mission to attack the target and is likewise subject to conditions considered in the above preference.

3. Once the target's method of attack table is identified and the fire unit grouping established, the selection process initiates a scan of the method of attack table in order of the preference indicated.

a. The first choice in the table will identify the preferred first choice of weapon system type and munitions to be used. If a fire unit with this weapon munition combination is available in Group 1 the fire unit is assigned if it has adequate munitions.

b. If several candidate fire units in Group 1 have the weapon/munition combination, a munitions-range workload factor is computed as follows for each candidate fire unit:

$$F_{MR} = N_R^i \frac{R_{MAX} - R_{TGT}}{R_{MAX} - R_{MIN}} \qquad (5\text{-}1)$$

where:

F_{MR} = munition-range workload factor

N_R^i = number of rounds of the munitions type specified for this weapon/munition combination

R_{MAX} = maximum range of weapon/munitions combination

R_{MIN} = minimum range of weapons/munitions combination

R_{TGT} = range to target.

The fire unit with the largest munitions-range workload factor is selected from the candidates for fire mission assignment.

c. If no fire units are available within the group with the weapon/munition first choice preference, of if adequate munitions are not available for the first choice preference, the next choice in the method of attack table is checked using the same logic. This process continues until a fire unit within Group 1 has been selected or until the choices in the method of attack table have been exhausted.

d. When all choices have been exhausted in the method of attack table for Group 1 fire units, and no fire unit has been selected, Group 2 fire units are identified; and the attack table is again scanned beginning with the first choice and continuing as before. This procedure continues until a fire unit is selected or until the last group is processed.

4. The hierarchy of the selection process can be summarized in terms of the competing selection factors arranged in the order in which they are applied.

- Target or mission request categorization as DS or other requests
- Fire unit mission grouping
- Weapon/munitions preference or effectiveness
- Munitions-range workload factor.

5. The selection of fire units is a dynamic process, and fire unit availability during the game period is a driving factor in determining the fire unit actually selected for the fire mission by the above logic scheme. Gamer control of fire unit selection within the TACFIRE mode occurs through DSL FIRE orders that render fire units unavailable while executing the DSL fire mission; through organizational assignment of DS, GS, GS/REINF, and REINF roles; through deployment or location of fire units; and through the initial preparation of method of attack tables and target priority tables.

6. If no fire units are available for an assignment, the target information is stored on the division's target list and will be processed again immediately after a fire unit becomes available. The logic process used when a target backlog exists is described in subroutine AFTFC2.

(e) Fire Mission Assignment. When a fire unit has been selected for a fire mission, the fire mission parameters on the method of attack table are set up in the Fire Unit Status Record [Paragraph 3b(1)(c)], and the fire unit processing is transferred to AFTFC2 for the individual scheduling of the volleys.

(2) Area Fire Tactical Fire Control, Section 2 (AFTFC2). Subroutine AFTFC2 is designed to represent the target selection process when a backlog of targets exists and a fire unit becomes available for a fire mission. The subroutine AFTFC2 generates fire missions from the target backlog list for those fire units that have completed fire missions or otherwise become available in the TACFIRE mode. AFTFC2 also generates the successive volleys for a fire unit currently engaged in a fire mission. Each time an active fire unit enters AFTFC2, its Unit Status File is used to update the information in the Fire Unit Status Record so that each volley assigned in a fire mission is subject to dynamic game sequencing. A macroflow of AFTFC2 is shown in Figure 5-6.

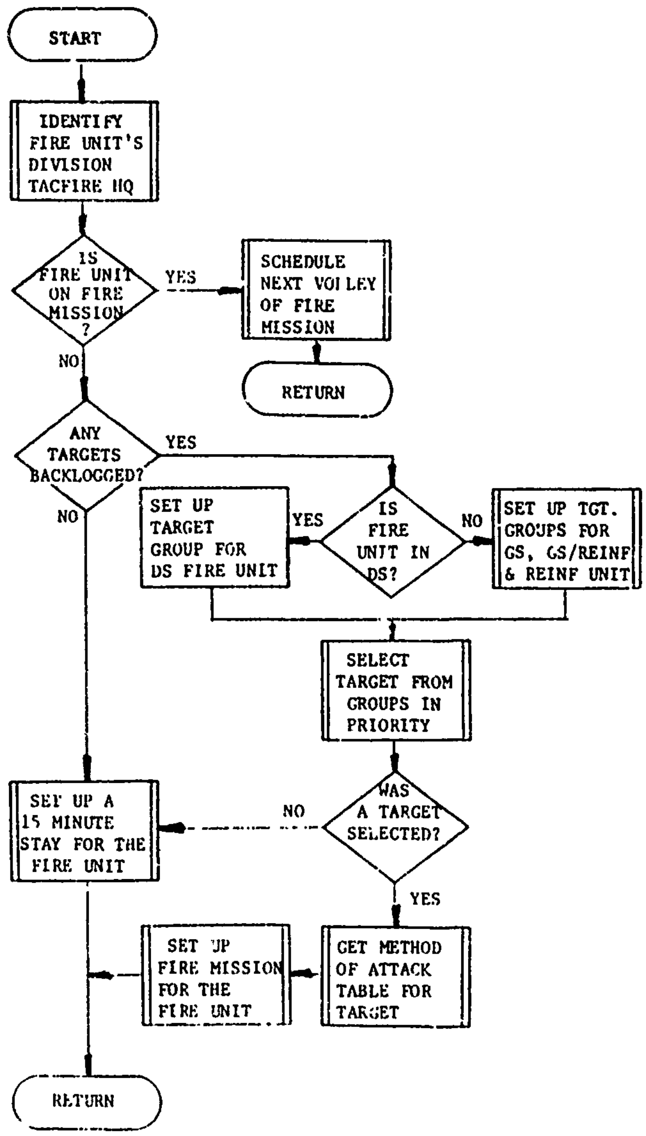


Figure 5-6. AFTFC2 Macroflow

(a) Fire Unit Activation. When a fire unit enters AFTFC2 after it has completed a fire mission or becomes available from a DSL fire mode or MOVE mode, the division target list is checked for a target backlog. If there are no targets the fire unit TACFIRE range code eliminator is set to zero to indicate there are no targets in the system on which the fire unit can fire. The fire unit is then scheduled for a 15-minute stay in the TACFIRE mode but can be activated by a new target entering the system in AFTFC1.

(b) Target Selection Process. When a target backlog exists a scanning of the target backlog list is initiated, and candidate target selection information is stored in the target selection array. The target list is scanned in three different sequenced passes that generate priority target groups based on the fire unit's organizational mission (i.e., DS, GS, GS/REINF, or REINF role).

1. If the fire unit is in a DS role, the initial scan ignores all targets except those that have been identified as being requested by the maneuver brigade or battalion of which the fire unit has been placed in direct support.

2. If no targets are found in the initial scan or if the fire unit is not in a DS role, the scan of the target list is set to select all targets that are identified as DS fire mission requests.

3. All targets not previously considered in a DS scan are included in the last scan. Thus, for fire units in DS roles the target backlog is grouped into three mutually exclusive groups as viewed from the fire unit:

- Group 1 - DS request for the fire unit being considered
- Group 2 - DS request for other DS fire units
- Group 3 - All other targets.

4. When a fire unit is in a GS, GS/REINF, or REINF role the targets are grouped into two mutually exclusive groups:

- Group 1 - DS requests for all DS fire units
- Group 2 - All other targets.

5. When a specific group containing several targets is processed, the target with the highest priority is considered first. If any targets have the same priority value, the target closest to the fire unit is selected. (It is in this screening process that a greater number of priority categories may be found desirable.)

6. Once a target has been selected, the method of attack table is scanned for the choice of munitions to use. (The fire unit's weapon system is already known.) The first choice encountered that is within the range limits, and for which the fire unit has at least enough munitions for the first volley, is the method of attack selected. If no choice is acceptable the target is deleted from the group being considered, and the reduced target group is scanned again. This procedure is repeated until the target group is exhausted or a target is selected and assigned. When a group is exhausted, the next specified target group is identified and processed in the same fashion until all the groups have been considered or until a target is finally selected and assigned.

(c) Moving Target Time Duration. Moving targets are checked each time a fire unit scans the target list for a new fire mission. If the estimated distance the target has moved since the last time it was detected is greater than 3000 meters, the target is dropped from the list and is not engaged. This parameter is representative of a target duration factor to establish a time window for moving targets [refer to Legal Mix IV study (Reference 3) and the TACFIRE Cost Effectiveness Study (Reference 2) for discussions of the time duration established for targets].

(d) Fire Mission Volley Scheduling. The portion of the subroutine handling the assignment of successive volleys proceeds as for DSL-ordered fire. During any fire mission, no fire unit will be interrupted and assigned to a higher priority target. Thus, fire units are unavailable for the duration of their current mission assignment.

c. Delivery and Assessment of Area Fires. The Area Fire Delivery and Assessment Submodel determines the units and discrete sensor systems that are located in the target area and within the effects area surrounding the center of impact of the volley, and computes the expected damage effects of the impacting rounds on equipment and personnel. A macroflow of the subroutine AREAFIRE, which performs these activities, is shown in Figure 5-7. All target damage and assessment of personnel casualties and equipment losses is accomplished on a per-volley basis. The assessment equations used to describe unit target damage and sensor target damage are discussed in the following subparagraphs.

(1) Preliminary Search Radius Screen. The center of impact of the volley is used in the submodel as the center of a preliminary screening circle of radius, R_S. This screening radius is dependent upon the weapon-munition combination type and upon the target being considered (i.e., unit or sensor targets). The units or sensors whose centers lie within this screening circle are then subject to further screening for possible casualties and equipment loss or failure.

(a) Unit Search Radius. To identify units that are potential candidates for further screening, the screening radius is set to 3500 meters plus the effects radius of the munitions combination used in the fire mission. Units centered within the screening radius are considered for assessment.

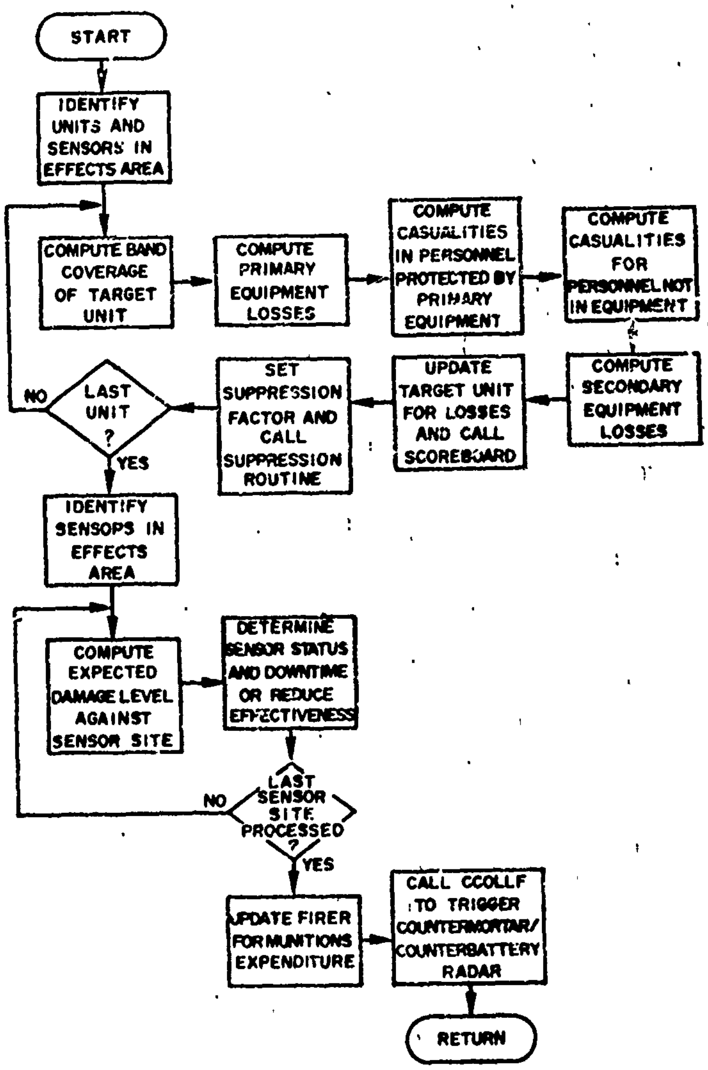


Figure 5-7. Area Fire Macroflow

The effects radius is defined for model purposes as the radius of a circle in which 99 percent of the effects of the volley are expected to occur, and is part of the constant input data load. Moving units are projected to their expected locations at the time of impact to ensure a timely assessment of area fire effects.

(b) Sensor Search Radius. Potential sensor systems to check for possible damage effects are located using a search radius fixed at 3000 meters. This distance is sufficient to ensure that negligible damage will result on any sensor system located outside this search radius.

(2) Assessment of Unit Area Targets. The computation of area fire damage effects to rectangular area target units is accomplished on a single band basis and the results summed to obtain a total unit loss. The geometry of the target unit and the band loss calculations are considered in the following subparagraphs.

(a) Band Assessment Geometry of Target Units. All units have a rectangular geometry and can contain up to four equal-area lateral bands. The outside dimensions, number of bands, and distribution of equipment and personnel within these bands are set dynamically in the DIVWAG system depending upon the type of unit and current mission or activity, i.e.:

. Move
. Stay
. Fire
. Attack
. Defend
. Withdraw
. Engineer.

A loss in personnel and/or equipment within various bands of the unit will reduce the density within these bands, but the band areas and percent distribution among bands will remain constant, regardless of the current strength of the unit. An example of the unit's geometry and band density, as illustrated in Figure 5-8, is described in Figure 5-9.

(b) Orientation Geometry of Target Unit. The orientation of the target unit is such that the forward edge is either in the direction of the current DSL move segment, facing the FEBA, or in a direction determined by the Ground Combat Model. An exception occurs when a unit has a WITHDRAW order. In this case the forward edge is oriented opposite to the direction of unit movement. The direction is specified by the angle α, as measured from the x-axis toward the direction of a line from the unit's center to the center point of the unit's leading edge.

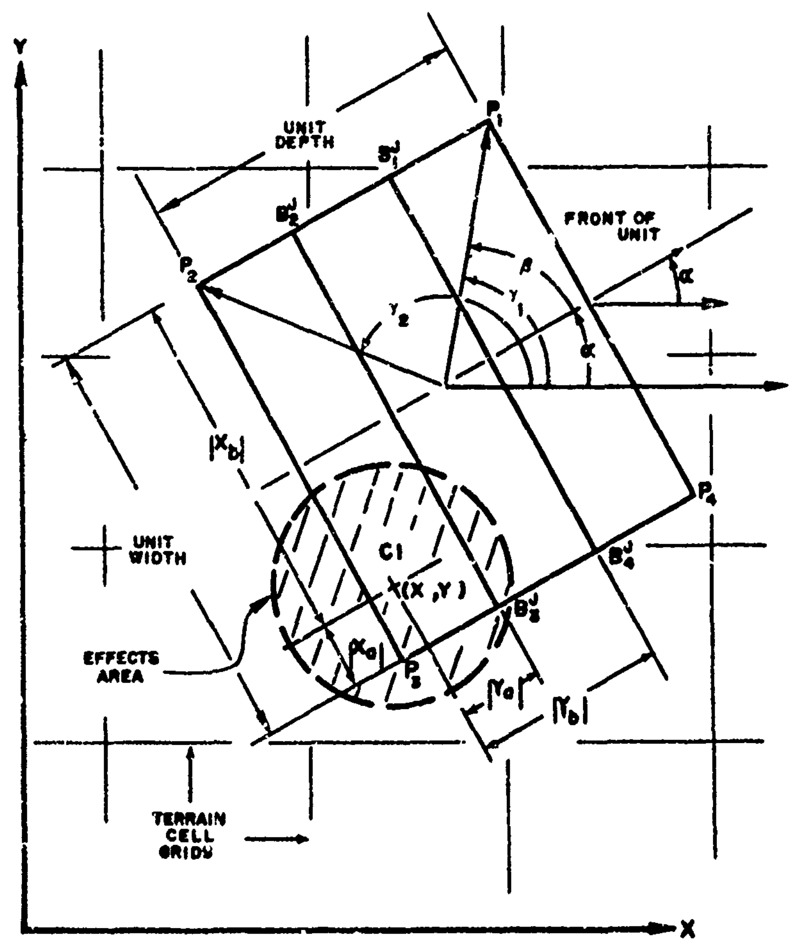


Figure 5-8. Target Unit Assessment Geometry

```
ACTIVITY INDEX  4 (ATTACK  )


WIDTH =    400 DEPTH =    600 NO. BANDS =  3


  PERSONNEL       DISTRIBUTION : 22230500 :    52 %    38 %    10 %
 FOR  ITEM      8 DISTRIBUTION :     6200 :     0 %     0 %   100 %
 FOR  ITEM     10 DISTRIBUTION : 42200000 :    68 %    32 %     0 %
 FOR  ITEM     16 DISTRIBUTION : 32230500 :    52 %    38 %    10 %
 FOR  ITEM     18 DISTRIBUTION : 35220300 :    58 %    36 %     6 %
 FOR  ITEM     19 DISTRIBUTION :     6200 :     0 %     0 %   100 %
 FOR  ITEM     62 DISTRIBUTION :   620000 :     0 %   100 %     0 %
 FOR  ITEM     65 DISTRIBUTION :  1204100 :     2 %    32 %    66 %
 FOR  ITEM     66 DISTRIBUTION :     6200 :     0 %     0 %   100 %
 FOR  ITEM     75 DISTRIBUTION :     6200 :     0 %     0 %   100 %
 FOR  ITEM     76 DISTRIBUTION : 42200000 :    68 %    32 %     0 %
 FOR  ITEM     77 DISTRIBUTION : 27260500 :    46 %    44 %    10 %
 FOR  ITEM     78 DISTRIBUTION :   620000 :     0 %   100 %     0 %

 ALL OTHER ITEMS DISTRIBUTED UNIFORMLY AMONG BANDS
```

Figure 5-9. Typical Unit Band Density

(c) Unit Assessment Calculations. The computation of target damage on bands of a unit is an adaptation of the casualty equation found in FM 6-141-1 (Reference 5) as used in the DIVTAG II assessment scheme, i.e.:

$$CAS_{ij}^{k} = N_i f_{ij} \left(1 - \exp \frac{-R_j^k(CEP) L_i^k N_r^k}{A_j} \right) \qquad (5\text{-}2)$$

where:

CAS_{ij}^{k} = casualties or equipment losses of type i in the jth band of the unit expected for munition type k

N_i = current strength or equipment on hand of type i

f_{ij} = percent of personnel or equipment type i in jth band

L_i^k = lethal area of kth type round or equivalent round against personnel in posture type i or against equipment type i

N_r^k = number of rounds or equivalent rounds of munitions type k in the volley

A_j = area of the jth band of the unit

$R_j^k(CEP)$ = fraction of the rounds of munition type k that is expected to cover the target jth band

All of the parameters except $R_j^k(CEP)$ of the equation are obtained from pregame data and the unit's status file. $R_j^k(CEP)$ is computed for each band of the unit and represents an approximate target coverage calculation. The equipment losses and personnel casualties are computed and stored as fractional numbers that are accumulated in the target unit's status file record. They are rounded off only for period output purposes.

1. Computation of $R_j^k(CEP)$. The computation of $R_j^k(CEP)$ depends on the delivery errors of the round or equivalent round. The CEP is defined as the radius of a circle inside of which 50 percent of the rounds will impact. These errors are approximated by a two-dimensional normal distribution with a standard deviation $\sigma = \sigma_x = \sigma_y$, where σ is related to the CEP data for the round as follows:

$$\sigma = \frac{\text{CEP(meters)}}{\sqrt{2\ln 2}} \qquad (5\text{-}3)$$

This relation results by assuming that the round or equivalent round dispersion can be approximated by a circular normal distribution density:

$$d(x,y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \qquad (5\text{-}4)$$

It follows from the definition of the CEP and Equation 5-4 that,

$$\iint\limits_{x^2+y^2 \le CEP^2} d(x,y)\,dxdy = \frac{1}{2}$$

or,

$$\frac{1}{2} = 1 - \exp\left(-\frac{CEP^2}{2\sigma^2}\right) \qquad (5\text{-}5)$$

Equation 5-3 follows from Equation 5-5 by solving for σ in terms of CEP. The value of $R_j^k(CEP)$ is obtained by numerically evaluating the integral:

$$R_j^k(CEP) = \iint\limits_{\text{area of band } j} d(x - x_I,\ y - y_I)\,dxdy, \qquad (5\text{-}6)$$

where (x_I, y_I) are the coordinates of the center of impact (CI) of the volley. (The dispersion of the CI for the volley has been included in the target location error simulated in the Intelligence and Control Model.) Evaluation of the double integral is accomplished by choosing a coordinate system such that the x-axis is parallel to the orientation of the band or unit. The two-dimensional integral then reduces to the product of two one-dimensional integrals as follows:

$$R_j^k = \left[\frac{1}{\sqrt{2\pi\sigma^2}} \int_{x_a}^{x_b} e^{-\frac{(x-x_I)^2}{2\sigma^2}} dx\right] \cdot \left[\frac{1}{\sqrt{2\pi\sigma^2}} \int_{y_a}^{y_b} e^{-\frac{(y-y_I)^2}{2\sigma^2}} dy\right]$$

$$= [I_x] \cdot [I_y] \qquad (5\text{-}7)$$

where:

$|x_a - x_b|$ = band width

$|y_a - y_b|$ = band depth

$|x_a - x_b|\,|y_a - y_b|$ = band area

R_j^k = used to denote R_j^k(CEP).

Evaluation of the individual integrals, I_x and I_y, then proceeds as follows:

Step 1. Compute the angles of orientation shown in Figure 5-8.

$$\beta = \text{ARCTAN}\left(\frac{\text{width of unit}}{\text{depth of unit}}\right) \qquad (5\text{-}8)$$

$$\gamma_1 = \alpha + \beta,\ \text{if } \gamma_1 > 2\pi,\ \gamma_1 = \alpha + \beta - 2\pi \qquad (5\text{-}9)$$

$$\gamma_2 = \pi - \beta + \alpha,\ \text{if } \gamma_2 > 2\pi,\ \gamma_2 = -\pi - \beta + \alpha \qquad (5\text{-}10)$$

$$r = \frac{1}{2}\,(\text{width}^2 + \text{depth}^2)^{\frac{1}{2}} \qquad (5\text{-}11)$$

Step 2. Determine the target unit's corner coordinates:

$$P_1(x_1,y_1) \quad x_1 = x_0 + r\cos\gamma_1 \tag{5-12a}$$

$$y_1 = y_0 + r\sin\gamma_1 \tag{5-12b}$$

$$P_2(x_2,y_2) \quad x_2 = x_0 + r\cos\gamma_2 \tag{5-12c}$$

$$y_2 = y_0 + r\sin\gamma_2 \tag{5-12d}$$

$$P_3(x_3,y_3) \quad x_3 = 2x_0 - x_1 \tag{5-12e}$$

$$y_3 = 2y_0 - y_1 \tag{5-12f}$$

$$P_4(x_4,y_4) \quad x_4 = 2x_0 - x_2 \tag{5-12g}$$

$$y_4 = 2y_0 - y_2 \tag{5-12h}$$

Step 3. Compute the corner coordinates of the jth band of the unit:

$$B_1^j \quad x_1^j = x_1 + [(j-1)/n](x_2-x_1) \tag{5-13a}$$

$$y_1^j = y_1 + [(j-1)/n](y_2-y_1) \tag{5-13b}$$

$$B_4^j \quad x_4^j = x_4 + [(j-1)/n](x_4-x_3) \tag{5-13c}$$

$$y_4^j = y_4 + [(j-1)/n](y_4-y_3) \tag{5-13d}$$

$$B_2^j \quad x_2^j = x_1 + (j/n)(x_2-x_1) \tag{5-13e}$$

$$y_2^j = y_1 + (j/n)(y_2-y_1) \tag{5-13f}$$

$$B_3^j \quad x_3^j = x_4 + (j/n)(x_3 - x_4) \qquad (5\text{-}13g)$$

$$y_3^j = y_4 + (j/n)(y_3 - y_4) \qquad (5\text{-}13h)$$

where: n = number of bands

Step 4. Determine the perpendicular distance from the center of impact to the lines forming the band edges:

$|x_a|$ = Distance from (x_I, y_I) to line $\overline{B_3B_4}$ (5-14)

$|x_b|$ = Distance from (x_I, y_I) to line $\overline{B_1B_2}$ (5-15)

$|y_a|$ = Distance from (x_I, y_I) to line $\overline{B_2B_3}$ (5-16)

$|y_b|$ = Distance from (x_I, y_I) to line $\overline{B_1B_4}$ (5-17)

Step 5. These distances are then normalized, and a numerical evaluation is made of the integral:

$$I_d = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{|d|}{\sigma}} e^{-\frac{z^2}{2}} dz \qquad (5\text{-}18)$$

for all four distances ($d = x_a, x_b, y_a, y_b$).

Step 6. The numerical values of I_x and I_y are then obtained in the following manner:

If $|x_a|$ is less than band width and $|x_b|$ is less than band width,

$$I_x = \left| I_{x_a} + I_{x_b} - 1 \right| \qquad (5\text{-}19)$$

otherwise:

$$I_x = \left| I_{x_a} - I_{x_b} \right| \qquad (5\text{-}20)$$

If $|y_a|$ is less than band depth and $|y_b|$ is less than band depth:

$$I_y = \left| I_{y_a} + I_{y_b} - 1 \right| \tag{5-21}$$

otherwise:

$$I_y = \left| I_{y_a} + I_{y_b} \right| \tag{5-22}$$

Step 7. The fraction of the rounds expected to impact in band j is finally obtained as:

$$R_j^k = I_x I_y \tag{5-23}$$

Once R_j^k has been computed for each band of the unit a check is performed to limit further calculations if R_j^k is less than 0.001 for a band. The lethal area of the round is also compared with the band area for each equipment or personnel assessment; and if the lethal area is greater than the target area, it is set equal to the target area to ensure that the kill probability per unit area never exceeds one.

2. Assessment of Primary Equipment Items. The assessment of equipment items is computed directly or indirectly, depending upon the identification of an equipment item as either primary or secondary. All primary items have an associated lethal area specified in the input data and are assessed using Equation 5-2. Once the primary items have been assessed, the secondary losses are computed from the secondary tables as:

$$CAS_j^{(2)} = \sum_i CAS_i^{(1)} f_{ij} \left(\frac{E_j^{(2)}}{A_j^{(2)}} \right) \tag{5-24}$$

where:

$CAS_j^{(2)}$ = losses of secondary equipment item j

$CAS_i^{(1)}$ = losses of primary equipment item i

f_{ij} = number of secondary equipment items type j authorized to primary equipment item type i

$E_j^{(2)}$ = secondary type j equipment on hand in unit

$A_j^{(2)}$ = secondary type j equipment authorized in unit

3. Assessment of Casualties. Personnel casualties are determined in a two-step process involving categories of personnel not protected by equipment on hand in the unit and personnel afforded protection by equipment. Figure 5-10 illustrates the breakdown of the two categories for a typical unit activity. The protection afforded is determined in the following steps.

a. Personnel are associated with equipment using the protection priority index to establish the order in which protection is given. The number protected by an equipment on hand item i, N_p^i, is:

$$N_p^i = E_i n_i^k \qquad (5\text{-}25)$$

where:

E_i = equipment type i on hand in unit

n_i^k = personnel afforded protection by one equipment item type i when the unit is in an activity k

The total number afforded protection, N_p^t is:

$$N_p^t = \text{Minimum} \left[\sum_i N_p^i \quad , N^t \right] \qquad (5\text{-}26)$$

where: N^t = the present strength of the unit.

BLUE PERSONNEL PROTECTION DATA

ACTIVITY INDEX 4 (ATTACK)

PERSONNEL NOT PROTECTED BY EQUIPMENT

POSTURE BREAKDOWN, UNWARNED :	STANDING	PRONE	FOXHOLE
	95 %	4 %	1 %
POSTURE BREAKDOWN, WARNED :	STANDING	PRONE	FOXHOLE
	9 %	90 %	1 %

TIME TO RETURN TO UNWARNED POSTURE : 2 (MINUTES)

PROTECTION OF PERSONNEL BY EQUIPMENT

PROTECTION PRIORITY	EOH INDEX	PERSONNEL PER ITEM	CASUALTIES PER LOSS
1	23	4	4
2	91	4	4
3	90	2	2
4	20	4	4
5	19	3	3
6	18	11	11
7	41	5	5
8	39	4	4
9	63	5	5
10	61	5	5
11	62	5	5
12	29	4	4
13	32	2	2
14	43	4	4
15	73	2	2
16	75	5	5

Figure 5-10. Typical Unit Personnel Protection

The number of casualties assessed when the equipment providing protection is lost, C_p, is given by:

$$C_p = \sum_i L_i l_i^k \qquad (5\text{-}27)$$

where:

L_i = equipment on hand item i losses

l_i^k = casualties per each equipment on hand item loss in activity k

and the summation over i is performed in order of the protection priority index and stops as soon as all personnel have been accounted for.

b. The personnel not protected by equipment, N_{up}^t, is:

$$N_{up}^t = N^t - N_p^t \qquad (5\text{-}28)$$

If N_{up}^t is greater than zero, these personnel are distributed in the posture categories warned or unwarned with standing, prone, or foxhole protection. The warned category is in effect if a prior volley had impacted within the unit before a time cutoff established in the data preparation has elapsed (in the example this time is 2 minutes). The distribution between standing, prone, and foxhole is also specified from input data as shown in Figure 5-10. The casualties sustained in each posture are computed using Equation 5-2. The sum of the unprotected casualties, C_{up}^t, is added to the protected casualties, C_p^t, to obtain the total casualties, C^t, i.e:

$$C^t = C_{up}^t + C_p^t \qquad (5\text{-}29)$$

(3) Assessment of Ground Sensors. In the DIVWAG system, several ground sensor types are not dynamically located within the boundary of the unit to which they belong and, therefore, are not subject to the assessment scheme for unit targets. These sensor sites are assessed individually to properly represent damage and degradation effects resulting from artillery-delivered area fire. The sensor systems are assessed using assessment calculations dependent upon the target being approximated either as a point type target or an extended area type target. These two techniques are described below.

(a) Assessment of Point Type Sensor Targets. Computations of damage against sensors whose physical dimensions are small relative to the effects area of a volley are based on a point target approximation. Representative sensor types would be ground based MTI, countermortar/battery radars, and ADA radar installation sites. The following computations describe the manner in which a sensor is determined to have sustained a certain damage level and the manner in which this damage level is used to determine resulting down time.

1. Damage Level Computations. The computation of the expected level of damage against a sensor site uses a damage function for a single round given by:

$$p(x_i,y_i,x,y) = e^{-\left[\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma_D^2}\right]} \tag{5-30}$$

where:

$p(x_i,y_i,x,y)$ = the probability that a round impacting at (x,y) will destroy the sensor site at (x_i,y_i)

and the lethal area, L, of the round is related to σ_D in the following manner:

$$L = \iint_{-\infty}^{\infty} p(x_i,y_i,x,y)\ dxdy \tag{5-31}$$

Performing the integral:

$$L = 2\pi \sigma_D^2 \tag{5-32}$$

and solving for σ_D results in:

$$\sigma_D = \left(\frac{L}{2\pi}\right)^{\frac{1}{2}} \tag{5-33}$$

Using Equation 5-4 to approximate the round-to-round delivery error about the center of impact of the volley, the probability of damaging the site for a single round is expressed as:

$$f(x_i,y_i) = \iint_{-\infty}^{\infty} d(x,y)\ p(x_i,y_i,x,y)\,dx\ dy \tag{5-34}$$

Sustitution of Equations 5-30 and 5-4 into Equation 5-34 results in the following:

$$f(x_i,y_i) = \frac{1}{2\pi\sigma^2} \iint_{-\infty}^{\infty} e^{-\left[\frac{x^2 + y^2}{2\sigma^2} + \frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma_D^2}\right]} dxdy \quad (5\text{-}35)$$

The integration of Equation 5-35 is straightforward and yields:

$$f(x_i,y_i) = \left(\frac{\sigma_D^2}{\sigma_D^2 + \sigma^2}\right) e^{-\frac{(x_i^2 + y_i^2)}{2(\sigma_D^2 + \sigma^2)}} \quad (5\text{-}36)$$

If the sensor is located at coordinates (x_s,y_s), and the center of impact of the volley is at (x_I,y_I), the x_i and y_i are given by:

$$x_i = x_s - x_I \quad (5\text{-}37)$$

$$y_i = y_s - y_I \quad (5\text{-}38)$$

and the separation, d_{IS} between the sensor site and center of impact of the volley is given by:

$$d_{IS} = (x_i^2 + y_i^2)^{1/2} \quad (5\text{-}39)$$

or:

$$(x_i^2 + y_i^2)^{1/2} = [(x_s-x_I)^2 + (y_s-y_I)^2]^{1/2} \quad (5\text{-}40)$$

Substituting Equation 5-40 into Equation 5-36 yields for the probability of damaging the site by a single round, the expression:

$$f(d_{IS}) = \frac{\sigma_D^2}{\sigma_D^2 + \sigma^2} e^{-\left[\frac{(x_s-x_I)^2 + (y_s-y_I)^2}{2(\sigma_D^2 + \sigma^2)}\right]} \qquad (5\text{-}41)$$

where the coordinates x_s, y_s, x_I, y_I are referred to the DIVWAG Model coordinate system. If Equation 5-41 represents the probability of damage occurring from a single round in the volley, then the probability of damaging the site from the entire volley of N_r^k rounds is given by:

$$F(d_{IS}) = 1 - [1 - f(d_{IS})]^{N_r^k} \qquad (5\text{-}42)$$

when a closed sheaf approximation is used (i.e., all rounds are fired at a common aim point.) The quantity $F(d_{IS})$ is used as a measure of the expected level of damage at the sensor site as a result of the fire mission volley. Figure 5-11 illustrates the damage levels for both the single round and for the entire volley as a function of separation of center of impact and sensor location for 6 artillery 155mm howitzers firing at a sensor site with rounds having a lethal area of $L \simeq 6000$ square meters and dispersion error of $\sigma \simeq 25$ meters.

2. Sensor Status Evaluation. The level of damage represented by Equation 5-42 is used to estimate the status of the sensor site for future operation. In order to retain more than a simple two-level destroyed or operational status, two intermediate levels of "temporarily destroyed" are incorporated in the model design. The determination of the sensor status uses the values in Figure 5-12. The last column in the table contains the expected downtime assessed to the sensor if it is judged to be temporarily damaged. The model logic is to determine the sensor site status from $F(d_{IS})$ and, if the site is temporarily damaged, to use linear interpolation between the limits in the table to select the actual downtime and to put the site in an inoperable status for this length of time (i.e., the time required to repair the sensor and return it to operational status).

(b) Assessment of Extended Area Sensors. The sensors assessed using this method are the unattended ground sensor (UGS) fields. These fields, as represented in the model, consist of four-sided figures containing uniformly distributed sensor types.

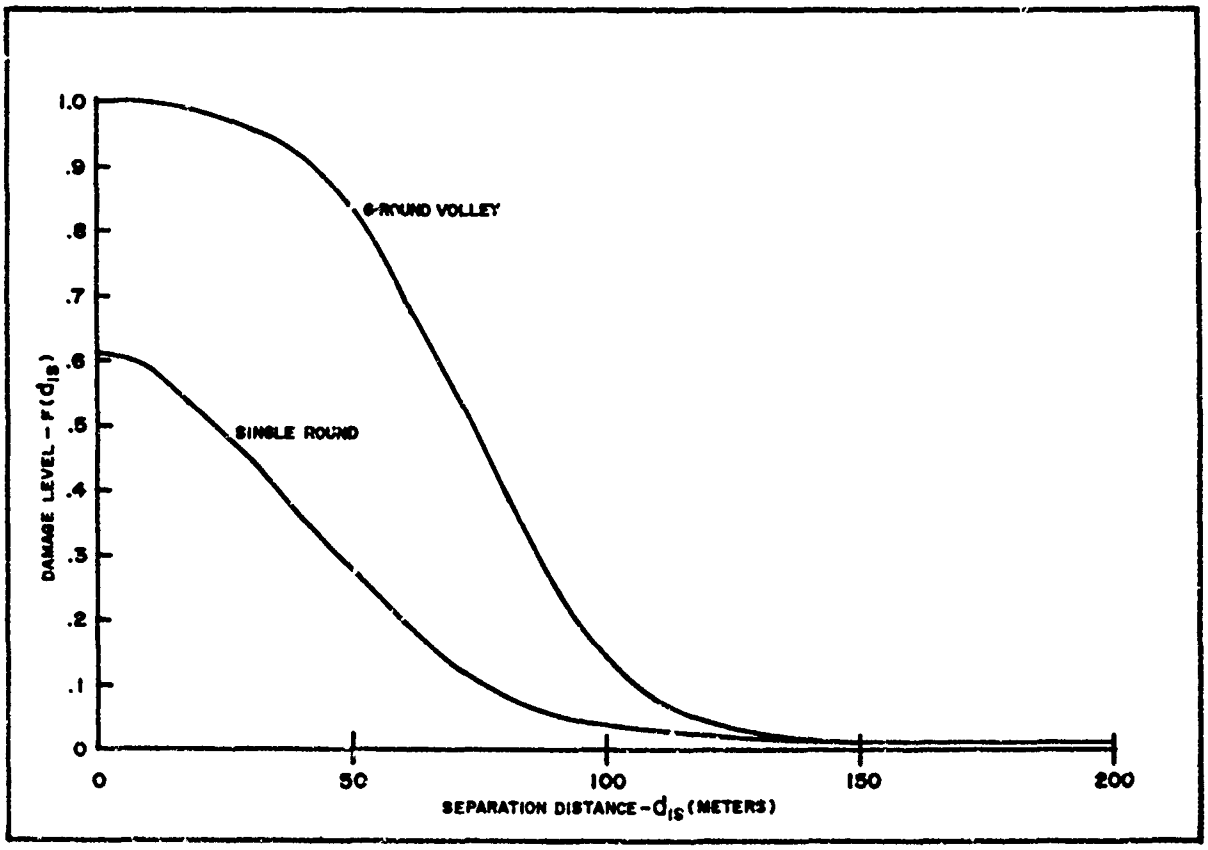


Figure 5-11. Damage Levels as a Function of Separation of Center of Impact and Sensor Location

$F(d_{IS})$	Sensor Status	Code	Downtime
$F \geq .5$	Destroyed	4	-
$.25 < F \leq .5$	Temporarily destroyed	3	3 - 12 Hours
$.1 < F \leq .25$	Temporarily destroyed	3	1 - 3 Hours
$F \leq .1$	No damage		0

Figure 5-12. Sensor Status Evaluation

1. Damage Function for UGS Fields. A circular "cookie cutter" damage pattern is used to evaluate UGS field damage. The radius of this damage pattern is currently set at 1000 meters.

2. Damage Estimate Against UGS Fields. The UGS damage radius is used to determine if any of the four corners of the UGS field lies within the damage function region. If three or more corners are found to lie within this radius, the field is considered completely destroyed and the sensor status code is set accordingly. If, however, only two corners are inside the damage function radius, subroutine CHORD is used to calculate the intersection of the damage function's circular boundary with the two sides of the field. These intersection points are then used as the new corner points of the UGS field, thus reducing the size and hence the effectiveness of the original field. If only one corner is found to be inside the damage function pattern, then the largest side attached to this corner is determined and the intersection of that side with the damage function boundary becomes the new corner of the UGS field, replacing the corner inside the damage area. These three cases are illustrated in Figure 5-13.

(4) Target Loss Update and Firer Expenditure Update. After the assessments for each band have been computed, they are summed and the total unit's personnel and equipment on hand strength is updated. The fire unit is also updated for munitions as:

$$M_k(\text{updated}) = M_k - N_r^k \tag{5-43}$$

where:

M_k = number of rounds prior to fire mission of equipment on hand type j in fire unit

N_r^k = number of rounds type k fired in the fire mission.

d. Fire Suppression of Unit Target From Area Fire. Units executing MOVE or FIRE orders suffer a disruption of activity when they receive enemy fire. The length of time the unit's activity is suppressed is dependent upon its type, its activity, and the type of fire. Tables of suppression time as a function of these variables are part of the constant data prepared pregame.

(1) Units Moving. If a unit is moving on the ground at the time it receives fire, it will be halted and required to stay for the amount of time indicated in the appropriate activity suppression table. This is accomplished by determining the distance the unit has traveled along its current model move segment at the time the enemy fire is received, terminating the segment at that point, and giving the unit a STAY order. The Movement Model is employed to perform the actual update of the unit's location and consumption of the proper amount of food and fuel. Upon expiration of the STAY order, execution of the MOVE event is resumed. The duration of the STAY is extended if other fire is received before it has elapsed.

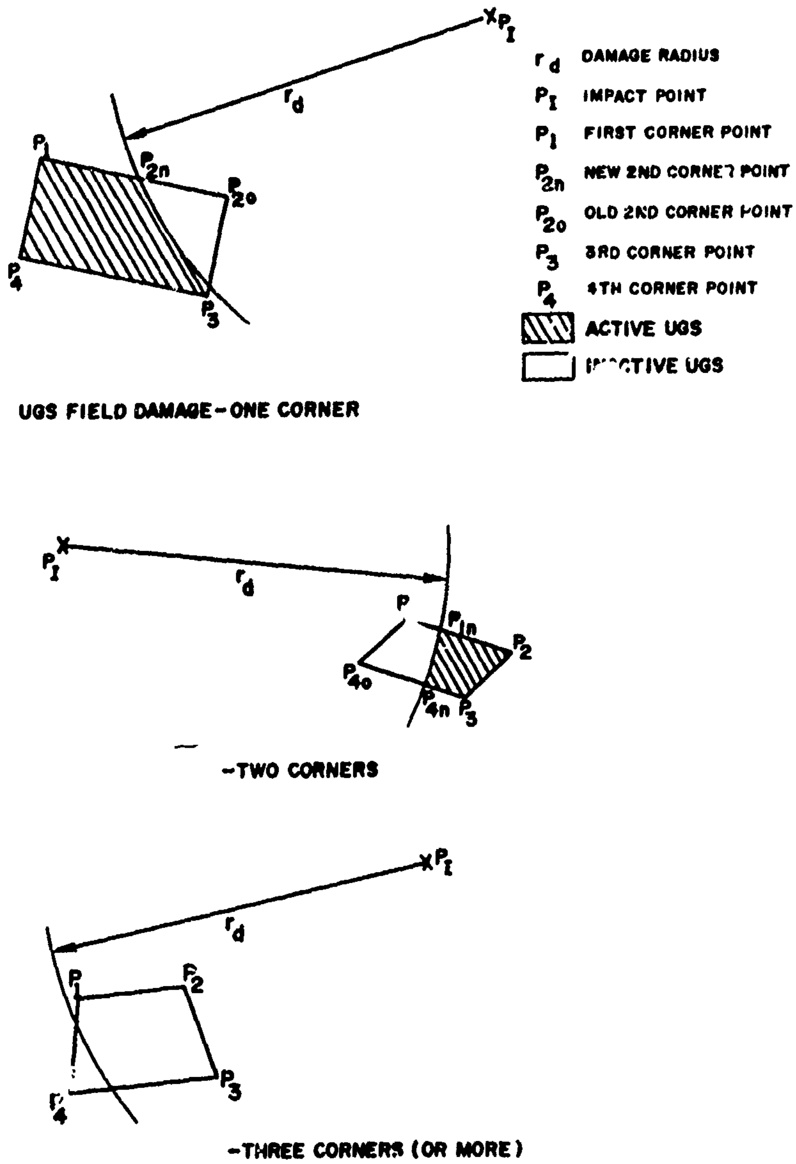


Figure 5-13. UGS Field Assessment Geometry

(2) Units Firing. A unit executing a fire order has a characteristic response time as described in Paragraph 2e. This response time, or time between volleys, is extended if the unit receives enemy fire. This is modeled by adding the suppression time to the response time or time between volleys. Again, the suppression time is selected from the tables described above. If a second volley of fire is received before the suppression time associated with the first has elapsed, the times will overlap.

4. REFERENCES:

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CHAPTER 6

AIR GROUND ENGAGEMENT MODEL

1. MILITARY ACTIVITY REPRESENTED:

a. General:

(1) The Air Ground Engagement Model determines the losses of both aircraft and ground targets resulting from all air-to-ground or ground-to-air interactions, except those associated with aerial reconnaissance (Chapter 3) and airmobile assault operations (Chapter 10). The Air Ground Engagement Model represents Army rotary wing and fixed wing aircraft, wich emphasis on the direct aerial fires (DAF)[1] role. High performance jet aircraft are represented in lesser detail, and only in the close air support (CAS)[1] role. The Air Ground Engagement Model is sensitive to changes in numbers, types, usage, and mixes of aircraft as well as to changes in the ground threat characteristics: weapons, deployment, and firing doctrine.

(2) The model treats the aerial attack of five target types under good or poor visibility conditions during daylight hours or night. Each of the 20 possible combinations of these factors is treated as a mission type, as enumerated in Figure 6-1. An additional factor, whether the aircraft does or does not penetrate enemy air space, makes a total of 40 mission types.

(3) For DAF missions, a first and a second choice aircraft/munition mix may be specified for employment. Losses or expenditures of DAF aircraft, fuel, personnel, and munitions are accounted for and are reflected in availability of resources for subsequent missions.

(4) CAS resources available are specified periodically during the game in terms of numbers of sorties of all-weather and good-weather aircraft to be made available in each 6-hour portion of a day. This sortie input is the sole constraint on CAS availability. High performance jet aircraft are assumed to be loaded with the most effective munition mix for each target type. Accordingly, no CAS aircraft/munition mix or other resources are specified or accounted for. CAS aircraft losses are, however, recorded for analysis.

b. Approach. An air mission is treated in the model in seven major segments. Activities represented within these segments are described below.

(1) Allocation of Mission Resources. In response to a request for a DAF mission, resources required to accomplish the mission are allocated based

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1. The term DAF in this chapter will be used to connote fires delivered by Army attack helicopters. The term CAS will connote supporting fires from high performance fixed wing aircraft, whether Red or Blue force.

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Nonpenetration Mission Code	Penetration Mission Code	Description of Target
01	21	Tank unit, daylight, good visibility
02	22	Tank unit, daylight, poor visibility
03	23	Tank unit, night, good visibility
04	24	Tank unit, night, poor visibility
05	25	Mechanized infantry (motorized rifle) unit, daylight, good visibility
06	26	Mechanized infantry (motorized rifle) unit, daylight, bad visibility
07	27	Mechanized infantry (motorized rifle) unit, night, good visibility
08	28	Mechanized infantry (motorized rifle) unit, night, poor visibility
09	29	Artillery unit, daylight, good visibility
10	30	Artillery unit, daylight, poor visibility
11	31	Artillery unit, night, good visibility
12	32	Artillery unit, night, poor visibility
13	33	Infantry unit, daylight, good visibility
14	34	Infantry unit, daylight, poor visibility
15	35	Infantry unit, night, good visibility
16	36	Infantry unit, night, poor visibility
17	37	Airbase, daylight, good visibility
18	38	Airbase, daylight, poor visibility
19	39	Airbase, night, good visibility
20	40	Airbase, night, poor visibility

Figure 6-1. Air Ground Engagement Model Mission Types

upon the mission type. The quantities of resources required for each mission are pregame inputs which can be set at any desired level. Normally, however, a minimum of two attack helicopters is needed to undertake a mission, in which case the mission would not be flown if only one aircraft were available. Support is allocated within a hierarchy of support relationships from the airbase[2] nearest the target which is capable of meeting the mission type requirements. Should insufficient appropriate resources be available, an indication to that effect is made so that alternative means of attacking the target may be employed. The time required for aircraft preparation including arming, fueling, and crew briefing is determined from pregame input data, and the time when aircraft are to be airborne is determined. While on the ground at the airbase, either before or during mission preparation, DAF aircraft are vulnerable to enemy attacks directed at the airbase. In the case of a request for a CAS mission, the remaining portion of the sorties allocated for the current 6-hour period must equal or exceed the number required to accomplish the mission, for the mission to be flown. Otherwise, a reject message is issued, as in the DAF case. No other resource constraints are considered for CAS, nor are CAS aircraft vulnerable on the airbase.

(2) Flight to the FEBA. When the aircraft are airborne, the formation flies from the airbase to a point near the front that is relatively safe from enemy air defense weapon systems. During this segment of the mission, no aircraft losses are considered. All aircraft leaving the airbase are assumed to arrive intact at the safe point. Consumptions of time and fuel are the only items considered during this mission segment (fuel is accounted for on DAF missions only).

(3) Penetration of Enemy Airspace. If the assigned mission requires penetration of enemy airspace, the fourth mission segment from the safe point to the target area is considered. Aircraft attrition due to enemy air defense weapons during this overflight of enemy airspace is calculated. The aircraft do not diverge from the assigned flight to the target area for the purpose of engaging enemy air defense weapons: thus, attrition to the aircraft and crews and consumption of fuel and time are considered on this mission segment.

(4) Target Strike. Upon arrival of aircraft at the target area, the fourth mission segment, attack of the designated target, is processed. Casualties may be inflicted on the attacking aircraft and its crews; on tanks, APCs, other vehicles, and personnel of the targeted unit; and upon air defense weapons in the vicinity of the target.

(5) Return to FEBA. Upon completion of the target strike, and if penetration of the enemy air space was required, the fifth mission segment returns the aircraft from the target area to a safe point within friendly

2. The term airbase is used synonymously with air force airbase or helicopter port or pad.

airspace. As in the flight to the target, attrition of the aircraft and crew and consumption of fuel and time are considered.

(6) Return to the Airbase (DAF Mission Only). The sixth mission segment returns the aircraft from the safe point to the airbase from which the mission originated. As in the flight to the FEBA, no aircraft losses are considered in this mission segment.

(7) Mission Completion (DAF Mission Only). The final segment is the mission completion. Aircraft landing, repair, and maintenance times are considered to determine when the aircraft will next be available for a new mission.

2. MODEL DESIGN:

a. Model Logic and Major Submodels:

(1) The basic logical flow of the Air Ground Engagement Model is predicated upon the automatic event sequencing logic fundamental to the DIVWAG system. The initial call to the Air Ground Engagement Model, in the form of a mission request, can be generated by either of two sources: DSL orders or the Intelligence and Control Model. A resource allocation submodel performs the necessary calculations to allocate aircraft to fly the mission, and schedules, as a DIVWAG event, the conditions that will pertain when the formation is airborne over the airbase. Each successive mission segment, as described in Paragraph 1b, is then treated similarly; at the time the preceding mission segment is scheduled to end, the results of that segment are calculated, appropriate Unit Status File records are updated, and the time at which the next mission segment is to be completed is scheduled. Chapter 1 contains a discussion of the DIVWAG event sequencing logic. Figure 6-2 represents the logical flow within the Air Ground Engagement Model in response to calls from the major DIVWAG executive routine.

(2) The Air Ground Engagement Model contains five major submodels to treat the seven mission segments described in Paragraph 1b. These include a resource allocation submodel (ATB) to treat the first mission segment, a friendly airspace overflight submodel (BTF) to treat the second and sixth mission segments, an en route attrition submodel (ENRATA) to treat the third and fifth mission segments, a target strike submodel (TORA) to treat the fourth mission segment, and a mission completion submodel (BTA) to treat the final mission segment. The specifications of these submodels are found in Paragraph 3.

b. Interactions with Other Models. The Air Ground Engagement Model interacts with the Intelligence and Control Model, the Combat Service Support Model, the Area Fire/TACFIRE Model and its Suppression Submodel, and the Ground Combat Model.

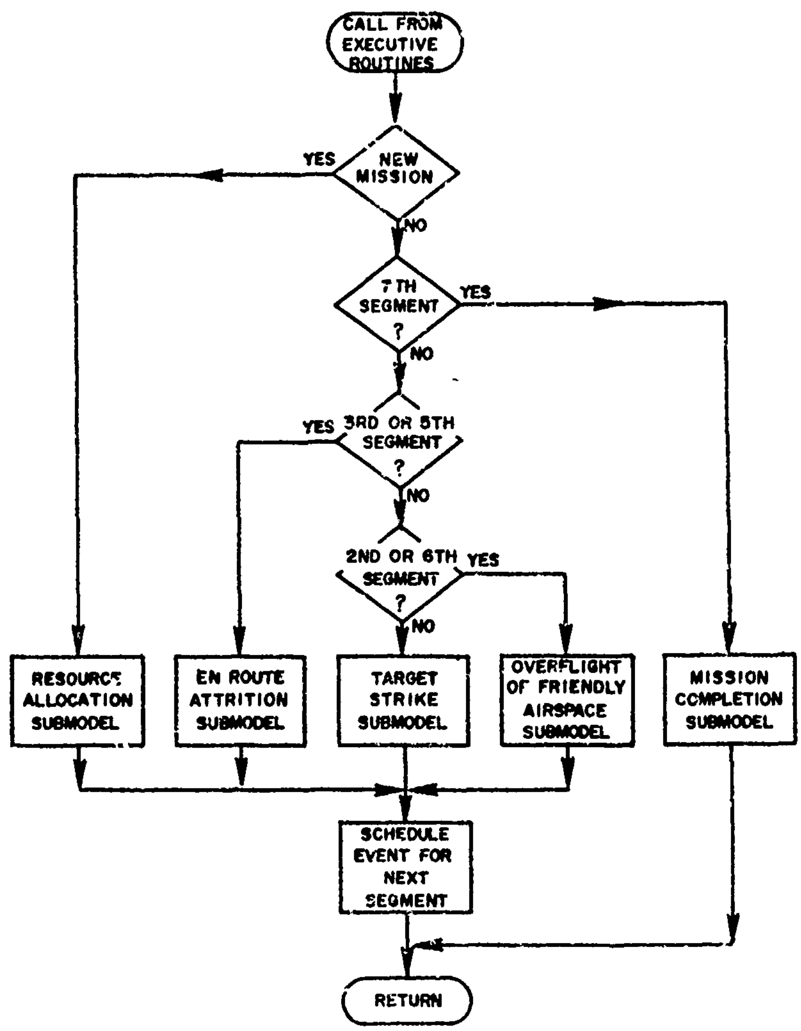

Figure 6-2. Air Ground Engagement Model Macroflow

(1) Interaction with the Intelligence and Control Model. A mission request from the Intelligence and Control Model contains information on the target's location, type, and activity, whether the target should be attacked by CAS or DAF, and whether a penetration of enemy airspace is required. If for some reason the Air Ground Engagement Model cannot perform the mission, a reject message is returned so that other firepower means may be directed against the target. A CAS mission request is denied if the available sorties for the current time period are less than the number required. For DAF the request is denied if the aircraft, munitions, personnel, or fuel required for the mission are not available. In addition, the Air Ground Engagement Model calls the Intelligence and Control Model at the beginning of each flight and again when the flight enters enemy airspace. These calls make the flight detectable by enemy sensors.

(2) Interaction with the Combat Service Support Model. The Unit Status File is the connection between the Air Ground Engagement Model and the Combat Service Support Model. The Combat Service Support Model resupplies aircraft, fuel, Army aerial fire support systems, munitions, and personnel to the airbases; and weapons, munitions, and personnel to the air defense units. This flow of men and materiel modifies the availability of personnel and equipment when an air mission is requested and the number of air defense weapons capable of firing at the aircraft when they penetrate enemy airspace.

(3) Interaction with the Area Fire/TACFIRE Model. The Area Fire/TACFIRE Model may assess losses to personnel and equipment on hand at an airbase or within an air defense unit. The effect is to modify the availability of items to fulfill requested DAF mission requirements and the number of air defense weapons that can fire against the aircraft.

(4) Interaction with the Ground Combat Model. When the target strike segment of an air ground mission is scheduled to occur during the target unit's participation within the Ground Combat Model, the ground combat assessment interval is interrupted at the scheduled time of the air strike. Assessments within the Ground Combat Model up to that point in time and assessment of the results of the air strike are then computed. After each such air attack ground combat continues, with the combined results of the ground combat assessment and the air strike assessment entered on the Unit Status Files of involved units.

(5) Interaction with the Suppression Submodel. Upon engaging the target unit, a suppression event is scheduled if the target is firing or moving. A delay of the movement or fire may result. The Suppression Submodel is described in Chapter 5.

c. Interaction with DSL. Two types of DSL orders interact directly with the Air Ground Engagement Model. One type of order (MISSION order) requests an air attack mission on a specific target. The other type of order (RETAIN order) asks that a specified number of aircraft of a required type be reserved

for undertaking one or more DSL-ordered DAF missions. Both of these order types are provided to specific airbases.

(1) MISSION Order. The MISSION order must, in all cases, specify the type (item code) and number of aircraft to be employed and the identity of the target to be attacked (target index number from the intelligence file of the division to which the airbase is assigned or attached). The desired attack time may be specified, at the gamer's option; otherwise, takeoff time will be the time the order is received.

(2) Translation of MISSION Order. The information in the MISSION order is passed to Subroutine AIRCNTRL to be processed. This processing yields the same type of mission request as generated by the Intelligence and Control Model [see Paragraph b(1), above], except that the request is, in addition, flagged as originating in DSL, and the airbase to be used is specified, together with the type and number of aircraft in the flight.

(3) RETAIN Order. The RETAIN order is applicable to DAF only and must specify the type (item code) and number of aircraft to be reserved. The RETAIN order will generally be prefaced with a STAY order which determines the point in time at which the reservation becomes effective. The RETAIN order affects those aircraft which are on hand in the designated airbase at the time the order becomes effective as well as aircraft entering the unit at some future time. Reserved aircraft cannot be used to fulfill air mission requests generated by the Intelligence and Control Model. The quantity of reserved aircraft is reduced by the number flown on DSL missions. A second or subsequent RETAIN order redefines the total number on reserve; unused reserve is not accumulated. An order to retain no aircraft will release any aircraft that may be on reserve status.

(4) Model Implementation. Implementation of these DSL orders within the Air Ground Engagement Model is further described in Paragraph 3b, below.

d. Environment:

(1) The Air Ground Engagement Model uses five DIVWAG environmental parameters: the visibility index, the terrain roughness and vegetation index, the forestation index, and the times, beginning of morning nautical twilight BMNT), and ending of evening nautical twilight (EENT).

(2) The visibility index is combined with BMNT and EENT to form a joint weather-light index, which is limited to four conditions. Visibility is defined in the Air Ground Engagement Model to be either good or poor. Visibility is good if the visibility index is greater than five; otherwise, it is poor. Light is determined by BMNT and EENT. Any time between BMNT and EENT is considered daytime. Other times are considered nighttime. Thus, the four weather-light conditions used by the Air Ground Engagement Model are: day, good visibility; day, poor visibility; night, good visibility; night, poor visibility. Roughness, vegetation, and forestation are used in the model

to degrade the effective number of air defense weapons that fire at overflying aircraft.

3. SUBMODEL SPECIFICATIONS:

a. General. The Air Ground Engagement Model performs a relatively limited number of calculations, generally of a geometric or a probabilistic nature. Most results generated by the model are the result of a direct look-up of data contained in an extensive data base, which must be prepared prior to the execution of simulated activities. Contents and form of the data tables are indicated within the descriptions of the model subroutines, where such information is essential to an appreciation of the model logic. Detailed data specifications are found in Volume VI, DIVWAG Data Requirements Definition.

b. Resource Allocation Submodel:

(1) Logical Flow. The basic logical flow of the Resource Allocation Submodel is shown in Figure 6-3. The incoming request for an air mission, whether originated by DSL or automatically by the Intelligence and Control Model, contains the estimated type of target unit, its estimated location and activity, and whether penetration of enemy airspace is anticipated. Automatic requests specify whether CAS or DAF is to be employed, whereas DSL-ordered requests specify the precise airbase, aircraft type, and number of aircraft to be used. The weather-light condition is then obtained and added to the information from the incoming request. This information is then used to translate the incoming request into one of the 40 possible mission types listed in Figure 6-1. Since the Intelligence and Control Model can identify 11 types of target units, while the Air Ground Engagement Model considers only five, a translation of target types is necessary. Types are equated by the model as follows:

Intelligence and Control Type	Air Ground Engagement Type
Infantry	Infantry
Mechanized infantry	Mechanized infantry
Armor	Tank
Reinforced task force	Tank
Tube artillery	Artillery
Missile artillery	Artillery
Air defense guns	Artillery
Air defense missiles	Artillery
Airbase	Airbase
Engineer	Infantry
Unknown	Infantry

For each of the 40 possible mission types, an input table specifies the typical resource requirements for attack of a typical size target unit.[3] For CAS,

3. Company size has been used to date.

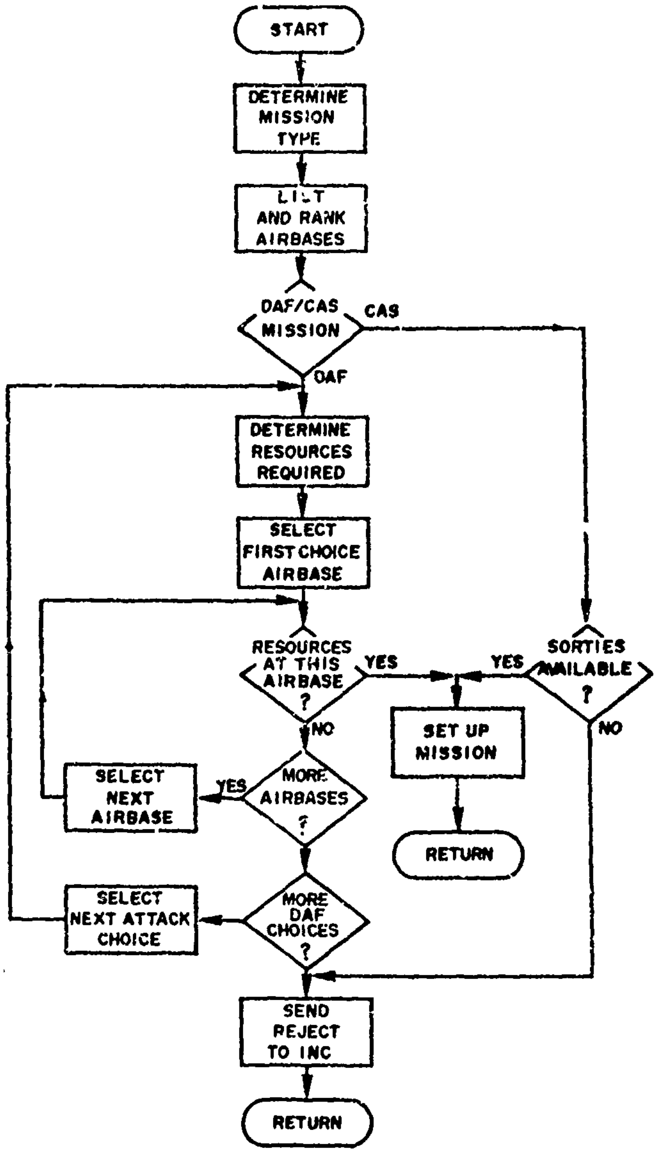

Figure 6-3a. Resource Allocation Submodel Logical Flow for Automatically Originated Mission

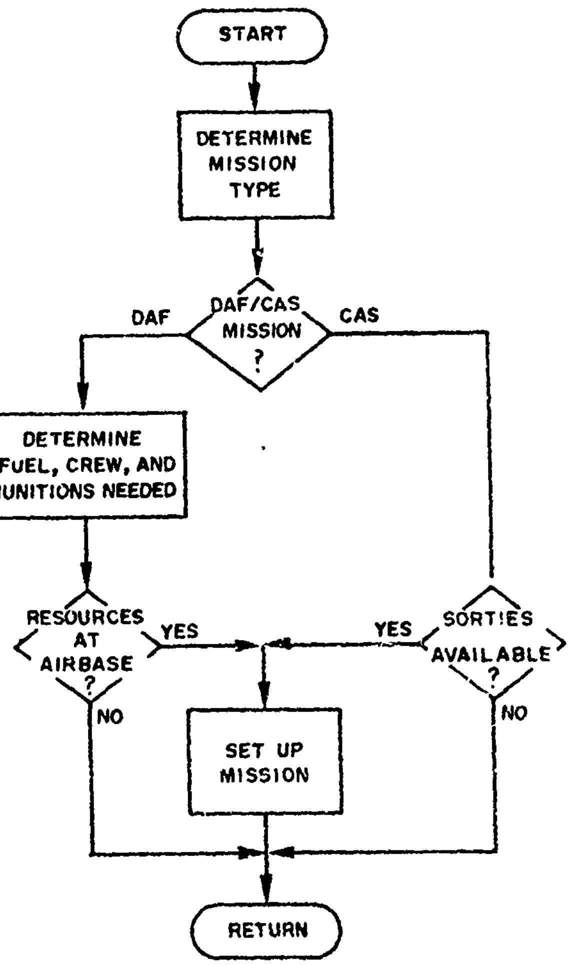

Figure 6-3b. Resource Allocation Submodel Logical Flow for DSL Originated Mission

only the required number of sorties is specified. For DAF, the required number of aircraft, personnel, munitions, and gallons of fuel is specified. If the request was originated automatically by the Intelligence and Control Model, the tabulated resource requirements are used. If the request originated in DSL, however, the type and number of aircraft are DSL-specified, and in this case, a ratio is struck between the number of aircraft specified by DSL and the number specified in the input table. This ratio is used in the case of DAF to modify tabular requirements for personnel, munitions, and fuel commensurate with the number of aircraft specified in the DSL. A determination of resource availability is then made as described in the next paragraph. If resources are not available for an automatically requested mission, a mission reject message is returned to allow for targeting by other fire support means. If resources are available, they are allocated for the assigned mission; and the necessary parameters for further simulation of the mission are generated.

(2) Resource Availability. The process of determining resource availability depends upon whether the request was DSL or automatically originated, and whether DAF or CAS is to be employed.

(a) Automatic DAF Mission Request. For each of the 40 mission types, both a first and a second choice of DAF aircraft type/munition types may be specified as part of the game constant data base, input before initiation of the game. For each choice, the minimum number of aircraft, personnel, munitions, and fuel (gallons) required to undertake the mission is specified. Each airbase is checked to see if the minimum first choice resource requirements are available at that airbase. (Resources on hand less those reserved for DSL missions are considered available for automatic DAF missions.) Airbases placed in direct support of the requesting unit are selected first and are ranked by proximity to the target. That airbase, if any, which is nearest the target and has sufficient available resources is chosen to mount the mission. If the mission request has not been satisfied, the process is repeated for those airbases in a general support role. If still no airbase qualifies, the process is repeated in an effort to apply the second DAF attack choice. If no airbase can meet either requirement, a mission reject message is generated to permit scheduling of other fire support means.

(b) DSL-Originated DAF Mission Request. For a DSL-originated DAF mission request, the type and number of aircraft desired to undertake the mission are specified by the gamer. By the process described in Paragraph b(1), above, the request is translated to one of the 40 mission types, and the tabular resource requirements for that mission type are adjusted according to the number of aircraft specified in the DSL request. The DSL request also specifies the airbase from which the resources are to come. All resources on hand at that airbase are considered available for a DSL mission. If resources on hand meet requirements, the mission is flown, and the number of aircraft flown is subtracted from those reserved, if any. If required (minimum) resources are not on hand, the mission is not flown, and a message is printed.

(c) DSL and Automatic CAS Mission Request. As part of the game data base, the number of CAS sorties available to each force, in four time blocks of 6 hours each starting at 2400, is input. These numbers may be changed between game periods if so required. For the Blue force, general availability of all-weather aircraft is assumed; for the Red force, two sortie allocations are made; one for all-weather aircraft and one for aircraft limited to operations under good weather-light conditions. In response to a request for a CAS mission, the number of sorties left in the current time block is checked. If all allocated sorties have been flown, a mission reject message is generated. The model does not permit good weather-light sorties to be used under other weather-light conditions.

(3) Resource Allocation:

(a) DAF Mission Requests. In addition to specifications of the minimum mission requirements described in Paragraph b(2)(a), above, the game data base contains an identically structured table, which specifies the maximum amounts of the same resources that may be allocated for a given mission type. Once an airbase capable of meeting the minimum requirements is found, resources are allocated from those available at the airbase up to the maximum levels specified. Some amount less than the maximum may be allocated if the maximum exhausts the airbase's currently available resources.

(b) CAS Mission Requests. CAS resources required to perform a given type mission are specified in the game data base only in terms of types and numbers of aircraft sorties. If required CAS sorties are available, the specified mission will be flown.

(4) Preparation Time. For automatic missions only, the Resource Allocation Submodel determines the time when aircraft are to be airborne.[4] This time is determined by adding preparation time to the current game time. Preparation time is obtained from the game data base, based on the type and number of aircraft allocated to the mission. These data are intended to represent typical times to brief crews, coordinate supporting fires, warm up aircraft, take off, and make up formations. Aircraft assigned to DAF missions are vulnerable to enemy attacks on the airbase until airborne. Attacks on CAS airbases are not considered.

(5) Continuation of Mission. To accomplish further simulation of the mission, a Unit Status File record containing the mission unit is constructed by the Resource Allocation Submodel. This procedure is a matter of programming convenience, done to facilitate keeping track of the aircraft allocated to the mission as they progress through the remaining mission segments.

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4. Takeoff time for DSL missions is determined by the DSL order [see Paragraph 2c(1)].

c. Friendly Airspace Overflight Submodel:

(1) Logical Flow. The basic logical flow of the Friendly Airspace Overflight Submodel is shown in Figure 6-4. The submodel determines the time the mission unit will reach a safe point, located near the FEBA, on the outgoing leg of a mission; or the time the aircraft will arrive at the home airbase from the same safe point on return from a mission. No attrition, maintenance, or air mishaps are treated during these segments of the mission.

(2) Calculation of the Safe Point. A safe point marks the simulated transition from friendly to enemy airspace. The point is developed by first constructing a line through the location of the specified target perpendicular to the FEBA. Then a line parallel to the FEBA, through the forwardmost enemy maneuver battalion, is constructed. The safe point is located X meters from the intersection of these lines, in a direction normal to the FEBA and toward the friendly area from the target. The distance, X, is determined from the effective range of enemy air defense weapons under the prevailing visibility conditions and the typical depth of deployment of these weapon systems. A schematic of the geometry involved is shown in Figure 6-5. The necessary calculations, documented in the following subparagraphs, require use of the slope of the battlefield and the list of forward maneuver battalions described in Chapter 2.

(a) The first calculation is of a safe distance, X_s, from the center of the forwardmost enemy unit to which an aircraft can fly and not be endangered by enemy air defense weapons. The safe distance, X_s, is found by:

$$X_s = R - D, \text{ if } R > D$$

$$X_s = 0, \text{ if } R \leq D \qquad (6\text{-}1)$$

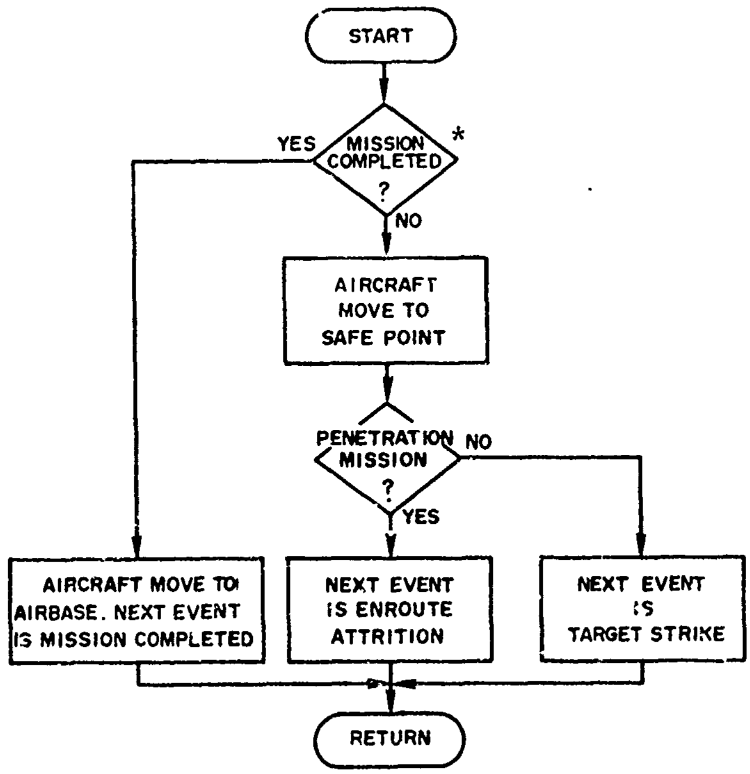
where:

R = greatest effective range under prevailing visibility conditions of any air defense weapon type in the force

D = typical deployment distance behind FEBA of that weapon type with effective range R.

(b) The X-intercept of a line parallel to the FEBA and passing through the point with coordinates (x,y) is found by Equation 6-2:

$$b = x + y \bullet s \qquad (6\text{-}2)$$



*Mission completed indicates attack of target is completed but aircraft are not back at the airbase.

Figure 6-4. Friendly Airspace Overflight Submodel Logical Flow

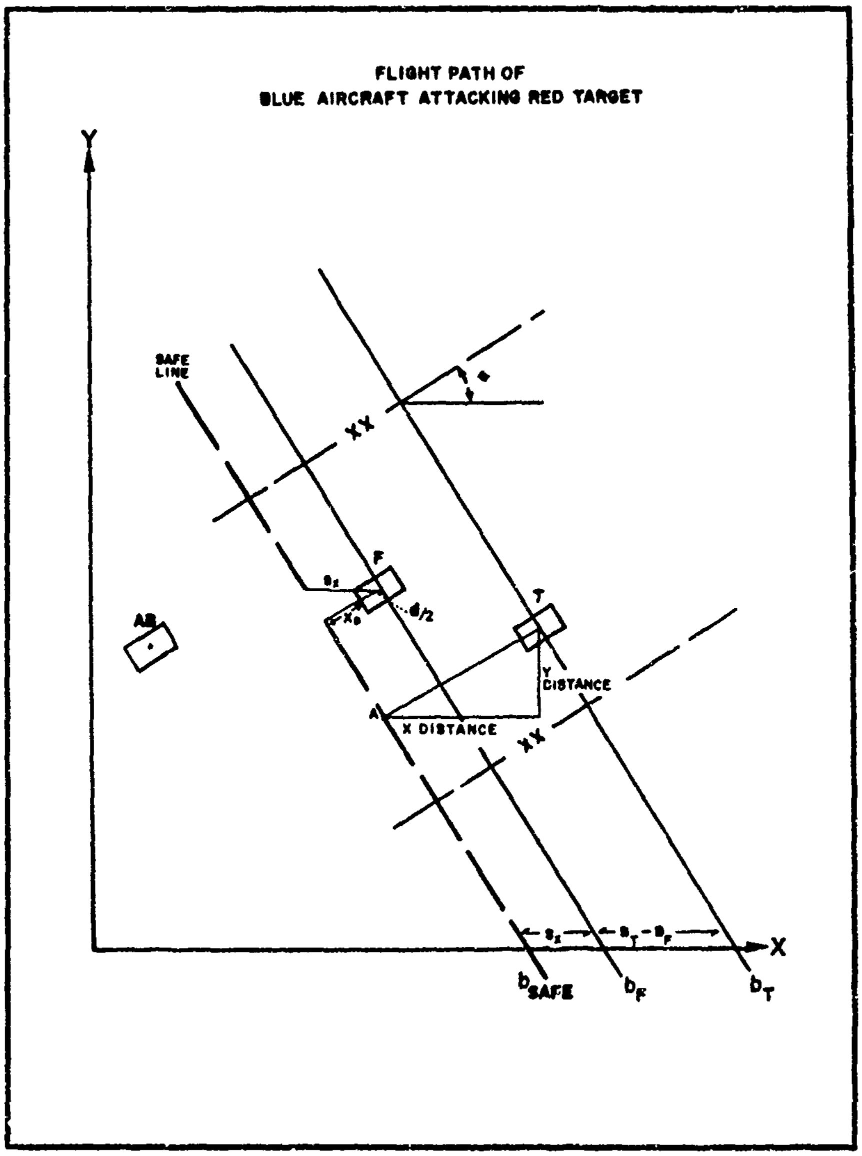


Figure 6-5. Schematic for Calculating Safe Point,
Blue Aircraft Attacking Red Target

where:

b = desired X-intercept

s = slope of the battlefield, or tan θ in Figure 6-5.

This equation is used to determine the X-intercept of lines through the centers of all forward maneuver units. The unit with X-intercept that is the closest to the X-intercept of the FEBA is the forwardmost maneuver battalion. The same equation is used to calculate the X-intercept of a line parallel to the FEBA through the target coordinates.

(c) A determination is made whether the target or the forwardmost maneuver battalion is closer to the FEBA. The safe distance is increased by one-half the depth of the forward unit to give a safe distance from the unit front. The horizontal projection of this distance on the X-axis is calculated using Equation 6-3:

$$S_X = (X_s \div d/2) \;/\; \cos\theta \qquad (6\text{-}3)$$

where:

S_X = horizontal projection of safe distance

d = depth of forward unit

X_s = defined in Equation 6-1

θ = see Figure 6-5.

(d) The distance from the safe point to the target, as projected on the X-axis, is the sum of S_X and the distance between the X-intercepts of the lines through the target and forwardmost unit, developed using Equation 6-2. This distance may be calculated as:

$$XDIST = S_X + |b_T - b_F| \qquad (6\text{-}4)$$

where:

XDIST = projection on X of distance from safe point to target

S_X = safe distance, from Equation 6-3

b_T = X-intercept of line parallel to FEBA passing through target

b_F = X-intercept of line parallel to FEBA passing through forwardmost unit.

(e) The actual distance from the safe point to the target, TDIST, and the projection of this distance on the Y-axis, YDIST, are given by Equations 6-5 and 6-6:

$$TDIST = XDIST / \cos\theta \tag{6-5}$$

$$YDIST = XDIST \bullet \tan\theta \tag{6-6}$$

where a current limitation is that θ must be defined to rotate from -90° through 0° to 90°.

(f) The coordinates of the safe point are calculated depending on the relative positions of b_T; the X-intercept of the safe line, b_{SAFE}; and the slope of the battlefield:

$$P_X = T_X + XDIST, \text{ if } b_T \leq b_{SAFE} \tag{6-7}$$

$$P_X = T_X - XDIST, \text{ if } b_T > b_{SAFE} \tag{6-8}$$

$$P_Y = T_Y + YDIST \tag{6-9}$$

if slope is greater than 0 and b_T is less than b_{SAFE} or if slope is less than or equals 0 and b_T greater than b_{SAFE}; and

$$P_Y = T_Y - YDIST \tag{6-10}$$

if slope is greater than 0 and b_T greater than b_{SAFE} or if slope is less than or equals 0 and b_T is less than b_{SAFE}, where:

P_X = X coordinate of safe point

P_Y = Y coordinate of safe point

T_X = X coordinate of target

T_Y = Y coordinate of target

XDIST, YDIST, b_T, b_{SAFE}, and slope are previously defined.

(3) Calculation of Flight Time. Cruise speeds for aircraft in various weather conditions are part of the game data base. These speeds are applied in the flight from the airbase to the safe point. Cruise speeds are applied to the straight line segment from the airbase to the safe point, and the required flight time is calculated by use of Equation 6-11. The same time and distance are used for the outgoing and incoming legs of a mission.

$$T = D / S \tag{6-11}$$

where:

T = time of flight

D = distance

S = airspeed.

d. En Route Attrition Submodel:

(1) General:

(a) This submodel calculates aircraft losses that may result from ground fire for any aircraft flight over enemy dominated terrain. Aircraft losses are classified into four categories depending on the type and severity of the damage. This submodel is called when DAF and CAS missions require penetration of enemy airspace. It determines aircraft losses inflicted by enemy air defense weapons as the aircraft move from the safe point to a point where attack of the target begins. The submodel is also used to determine aircraft losses that occur as the formation returns to friendly territory after mission accomplishment. Flight time is also calculated.

(b) The details of each specific air ground interaction are not simulated. No air defense or other ground weapons are attrited by activities simulated in the submodel; however, losses of air defense weapons prior to the flight are reflected.

(c) Input data tables provide the number of air defense weapon rounds per weapon that will be fired under a certain set of engagement conditions. Other tables provide factors for modifying both the number of weapons engaging and the number of rounds fired per weapon, as a function of the actual circumstances of each engagement. Number of rounds fired by each weapon type is distributed over all aircraft in the flight and then translated into probable number of hits by the use of input data on average slant range and weapon accuracy. Aircraft losses, in four kill type categories, are then developed by input data on the average vulnerable area of each aircraft type to each weapon type at average slant range.

(d) Three air defense zones are established within the program for programming convenience only. They have no impact on the attrition results generated. Zone 1 currently extends from the safe line to a depth of 3 kilometers beyond the FEBA. Zone 2 is another 3 kilometers in depth, and Zone 3 extends from the back edge of Zone 2 to the rear boundary of the division.

(2) Model Logic:

(a) Only those enemy units designated by a "D" in the last character of their UTD are considered to have air defense capability for purposes of the En Route Attrition Submodel. Within such enemy units, only those air defense weapon types whose unit center is within maximum effective weapon range of the flight path are considered. Air defense weapon types and their ranges are specified in the constant data input. Based on the flight path, weapon types in range are identified; and a count is made, on a current status basis, of the number of weapons in range. This current weapon count is performed for each air defense weapon type, covering the entire flight through hostile airspace. Figure 6-6 shows an example of one of the envelopes around the flight path which includes all designated air defense weapons of a specific type. The envelope in this figure is for a weapon type whose maximum effective range, for the current weather-light condition, is RE. The distance, Y, represents aircraft munition release standoff distance, if any. The flight path through hostile airspace is from point A to point B.

(b) The number of air defense rounds per weapon that will be fired at a flight traveling at a basic speed, in an average engagement, is obtained from an input table for each weapon type. These numbers are to reflect a single, base aircraft speed and the rate of fire capabilities of each air defense weapon, and are provided for each of the four weather-light conditions. These numbers assume that flight altitude is essentially an optimum for the weapon, that the terrain is flat and devoid of vegetation or forestation, and that adequate ammunition is available. All other conditions are assumed to be at a normal level. These numbers of rounds fired per weapon are then multiplied by the number of weapons of each type which were found as described in the previous subparagraph to be within range of the flight path. This process yields base numbers of aggregated rounds fired by each weapon type.

(c) The base numbers are then subjected to degradation and modification factors for conditions currently prevailing. Base numbers of rounds fired are first constrained within the number of rounds currently on hand within the pertinent units. Factors from an input table are then applied to reflect, for each weapon type, the fraction of weapons in range which would be likely to engage the target under the current light condition and weapon unit posture (attack or defend); and the impact of actual flight speed (as opposed to base aircraft speed) on the number of rounds fired. Another input table provides, for each weapon type, factors reflecting the estimated impact of actual terrain roughness and vegetation, forestation, and aircraft altitude

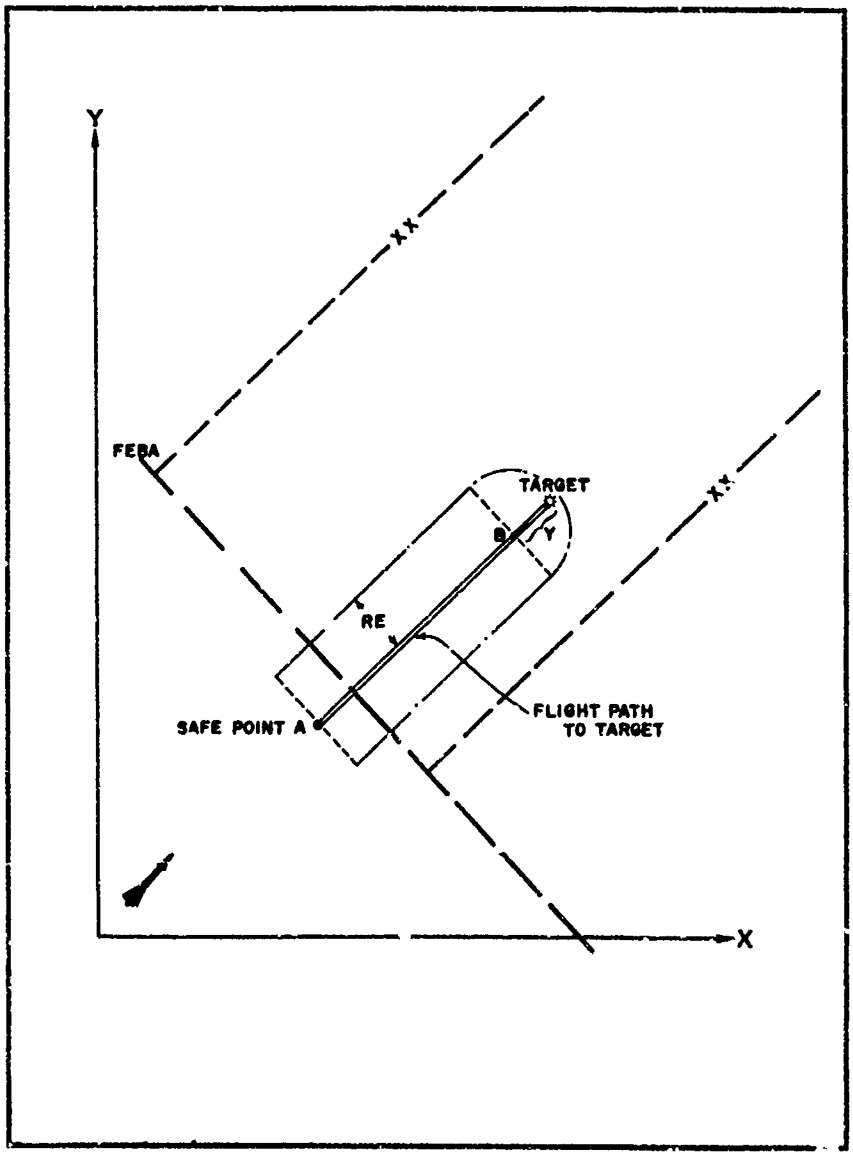


Figure 6-6. Determination of the Number of Air Defense Weapons within Range

on weapon effectiveness. This table contains three sets of data, each characteristic of the altitude conditions expected to be associated with the respective type of flight--DAF, reconnaissance, and CAS. Each set of data allows for three forestation categories (sparse, F=0; medium, F=1; and dense, $F \gtrsim 1$)[5] and two terrain roughness categories (good, $RV \leq 5$; and rough, $RV \gtrsim 5$). A factor is extracted from this table for each terrain cell overflown, and an average factor is then applied for the flight through enemy airspace. The result of applying these factors to the ammunition-constrained base number is to yield the number of rounds from this weapon type that will reach the vicinity of the flight. This result is then divided by the number of aircraft in the flight (assuming equal distribution) to give the number of rounds (N) of this type reaching the vicinity of one aircraft.

(d) To calculate the probability that one of these rounds will hit a vulnerable portion of an aircraft, further data from the input tables are obtained for this weapon type. These data include an average weapon error, in mils, and an average slant range of engagement. Both of these items are input for each of the four weather-light conditions. For convenience in calculation, the probability of <u>no</u> hit is used instead of the probability of hit. The probability that one of these rounds will not impact within a 1-meter square area will then be (Reference 2):

$$e^{-\frac{1}{2\pi S^2 \bullet M^2}} \qquad (6\text{-}12)$$

where:

S = average slant range in kilometers of engagement by this weapon type

M = average weapon error in mils for the weapon type.

(e) The number of rounds that will probably not hit a 1-meter square area on one aircraft is then Equation 6-13 raised to the power equal to the number of rounds (N) reaching the vicinity of the aircraft, or:

$$e^{-\frac{N}{2\pi S^2 \bullet M^2}} \qquad (6\text{-}13)$$

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5. See Chapter 2 for definitions of index values.

(f) Vulnerable area data for each weapon type versus each aircraft type are obtained from another input table. This table contains data (arranged cumulatively) for four kill type categories. The data are average values based upon the average slant range of the weapon (with the resulting projectile striking velocity) and assume a mix of aspect angles appropriate to the type of weapon and aircraft.

(g) The probability of survival of one aircraft of this type against this weapon type, for a given kill category, is then:

$$e^{-\frac{N \bullet VA}{2\pi S^2 \bullet M^2}} \qquad (6\text{-}14)$$

where:

VA = average vulnerable area of this aircraft type to a hit by this weapon type at the average slant range

(h) For the initial kill category, the probability of survival to all weapons is the product of the probabilities for each weapon type. The number of aircraft kills in the initial category is then the number of aircraft of this type in the flight multiplied by the quantity one minus the probability of survival to all weapons. For other kill categories, results are obtained similarly, except that prior category kills are removed, since the vulnerable area data were cumulative.

(3) Aircraft Kill Equation:

(a) Equation 6-15 represents the final aircraft loss calculation steps used by the Air Ground Engagement Model for the first kill category.

$$T_{km} = \sum_{k=1}^{k_{max}} N_k \left[1 - \prod_{i=1}^{i_{max}} P_{s_{ikm}} \right] \qquad (6\text{-}15)$$

where:

T_{km} = expected number of type m kills to aircraft type k

N_k = number of type k aircraft flying mission

$P_{s_{ikm}}$ = probability that a single type k aircraft will survive a type m kill from all type i air defense weapons contained in the flight envelope (see Figure 6-6)

i_{max} = number of air defense weapon types

k_{max} = number of aircraft types on mission (currently assumed to equal one).

(b) Four kill categories are considered in the model: A-kill (catastrophic kill), B-kill (forced landing), C-kill (mission abort), and D-kill (hit, but minor damage). When an aircraft suffers an A-kill, it crashes because of the damage inflicted by the defending air defense weapons and is not recoverable for future use. Type B-kill forces the aircraft to land (powered or unpowered) because of damage, or forces it to make a precautionary landing because of an automatic warning signal indicating trouble. If the downed aircraft has penetrated enemy airspace, it is not recoverable and is considered destroyed. If no penetration of hostile territory occurred, the downed aircraft is recovered after an appropriate delay time. It can then be used in future engagements. When a type C-kill occurs, the aircraft is forced to discontinue its mission because of damage to the aircraft or because of a pilot or copilot casualty. In this case, the aircraft immediately breaks off its engagement with the target and returns to its base. Type C-kills are susceptible to additional attrition from air defense weapons on the return trip. Aircraft suffering type D-kills are considered able to complete their mission. A repair time is imposed on them when they return to their airbase.

(4) Probability of Aircraft Survival Equation. The probability of survival term used in Equation 6-15 can be resummarized as shown in Equation 6-16. The same subscripts are used as in Equation 6-15.

$$P_{S_{ikm}} = e^{-\frac{N3 \bullet F1 \bullet F2 \bullet F3}{AC} \bullet \frac{1}{2\pi \bullet S^2 \bullet M^2} \bullet VA} \qquad (6\text{-}16)$$

where:

N1 = number of rounds per weapon of type i fired in an average engagement at base aircraft speed (from input)

N2 = number of weapons of type i in range of the flight path

N3 = product of N1 multiplied by N2, constrained within number of rounds currently on hand in the pertinent units

F1 = fraction of weapons likely to engage under the current light condition and weapon unit posture

F2 = factor to adjust to rounds per weapon fired at actual aircraft speed (versus base speed)

F3 = average factor for weapon effectiveness at actual altitude, forestation, and average terrain roughness and vegetation

AC = number of aircraft of type k in the flight

S = average slant range in kilometers of engagement by weapon type i

M = average weapon error in mils, weapon type i

VA = average aircraft area vulnerable in square meters, to a hit by this weapon type, at average slant range, for aircraft type k and kill type m.

Equation 6-16 is based on the assumption that hit probability may be reasonably approximated by a circular normal distribution without bias as described in References 1 and 2.

(5) Calculation of Flight Time. Flight time in enemy airspace is calculated for flight from the safe point to the target and return from the target to the safe point in the same manner as described in Paragraph c(3), above. Flight time from takeoff to target establishes the time of target attack. In the case of DAF, total flight duration affects the availability of DAF resources for subsequent missions.

e. Target Strike Submodel:

(1) Approach. This submodel determines outcomes of engagements between aerial attackers and ground based weapons in terms of aircraft losses, munition expenditures, and losses inflicted on the ground target. The detailed interactions of the aircraft and ground forces are not explicitly simulated. Rather, the complete engagement results are extracted from a series of lookup tables, which are prepared pregame from results obtained from high resolution simulations for engagements under similar conditions (Reference 4). Prior to entering the lookup tables to determine engagement results, the number of aircraft surviving the flight to the point from which the target will be attacked is compared with the abort criterion (minimum number of aircraft) to see if the mission will be performed. If the mission is aborted the aircraft are returned to the mission safe point without first attacking the target. A mission is not aborted if the mission did not require some penetration of the enemy airspace.

(2) Engagement Result Tables. Input to the engagement result tables consists of 456 situations. These situations include five target types under each of the four weather-light conditions of daytime, good visibility; daytime, poor visibility; nighttime, good visibility; and nighttime, poor visibility. Targets include a tank unit, a mechanized infantry unit (motorized rifle unit), an infantry unit, an artillery unit, and an airbase. These five target types and four visibility conditions define the 20 mission types shown in Figure 6-1. For each mission type these situations consist of one of three attack aircraft/munition mixes and one of two placements of air defense weapons in the target area. Five postures are possible for each mission type

against the tank unit, the mechanized infantry unit, and the infantry unit targets (assembly area, attack, defend, on road, delay). These three target types account for 360 of the 456 situations in the result tables (12 mission types, 2 air defense placements, 3 aircraft/munition mixes, 5 postures). For the artillery unit target three postures are used: on the road not firing firing artillery tubes, and firing missiles, giving a total of 72 situations (4 mission types, 2 air defense placements, 3 aircraft/munition mixes, 3 postures). For the airbase as a target, posture is not considered; hence, this case adds 24 situations (4 mission types, 3 aircraft/munition mixes, 2 air defense placements). The contents of the engagement results table are shown in Figure 6-7. Losses to attacking aircraft, defending air defense weapons, and the target itself are all contained in the 54 information items.

(3) Use of Engagement Result Tables:

(a) Data in the engagement result table are adjusted to account for the specific number of aircraft that attack the target and the true strength of the enemy force in the target area. The fractional number of effective aircraft remaining if there was penetration is divided by the number of aircraft upon which the data were derived to get an adjustment factor. This adjustment factor is further modified by multiplying it by the enemy percent strength. This total adjustment factor is used as a multiplier of the tabular data in the engagement result table.

$$\text{RESULT} = \frac{n}{N} \bullet \frac{P}{A} \bullet E_i \tag{6-17}$$

where:

n = number of aircraft remaining on the mission when the formation reaches attack point; A-, B-, and C-type kills have been attrited

N = number of aircraft on which this particular situation in the engagement result table is based

P = present strength of the target unit

A = TOE strength authorized for the target unit

E_i = entry i in the engagement result table.

Each of the first 52 items in the engagement result table is premultiplied as shown in Equation 6-17.

(b) After the results of the air strike have been determined, the attrited air defense equipment is distributed among the target unit and its supporting air defense units. For each air defense weapon type, losses are distributed proportionately to the number of weapons in a unit. To

Field	Description	Field	Description
	A-kills		Tanks killed
1	by < 23mm	29	by guided missile
2	by 23mm		
3	by > 23mm		APCs killed
4	by SAM	30	by guided missile
		31	by other
	B-kills		
5	by < 23mm		Vehicles killed
6	by 23mm	32	by guided missile
7	by > 23mm	33	by other
8	by SAM		
		34	Personnel killed
	C-kills		
9	by < 23mm		Air defense weapons killed
10	by 23mm	35	type 1
11	by > 23mm	36	type 2
12	by SAM	37	type 3
		38	type 4
	D-kills	39	type 5
13	by < 23mm	40	type 6
14	by 23mm	41	type 7
15	by > 23mm	42	type 8
16	by SAM	43	type 9
	Aerial munition expended		Air defense munition expended
17	type 1	44	type 1
18	type 2	45	type 2
19	type 3	46	type 3
20	type 4	47	type 4
21	type 5	48	type 5
22	type 6	49	type 6
		50	type 7
	Aerial munition lost	51	type 8
23	type 1	52	type 9
24	type 2		
25	type 3	53	Number of aircraft flying mission
26	type 4		
27	type 5		
28	type 6	54	Duration of engagement minutes x 10^2

Figure 6-7. Engagement Results Table

determine the supporting units, a circle with its center at the coordinates of the target unit is drawn. The radius of this circle is twice the standoff distance, y, for the engagement. All enemy units containing air defense weapons whose coordinates fall within the circumference of this circle are considered to be supporting units.

(4) Ground Combat Model Interaction. If the target unit is engaged in ground combat, the Ground Combat Model performs an assessment up to the time of the air attack. The Target Strike Submodel then assesses the effects of the air attack. On subsequent intervals the Ground Combat Model will integrate the effects of the aerial attack with the ground weapon systems effects.

(5) Return. After exiting from the Target Strike Submodel, any remaining aircraft are flown back to the airbase or the mission safe point, as appropriate.

f. Mission Completion Submodel (DAF Aircraft Only). When the aircraft have arrived at a point over the airbase and are ready to land, the Mission Completion Submodel is called. This subroutine determines the landing time required, which includes taxi time to the aprons used for parking or storing the aircraft at the base. By use of tabular data, the subroutine determines the time when each of the returning aircraft (or recoverable aircraft) can be listed as available for another mission. Differences in airfield capabilities are not considered. It is assumed that the base capabilities are compatible with the aircraft types. Generally, the times in the table 11 permit aircraft with no damage to be available as soon as the required postflight maintenance time for the number of flying hours has passed. The maintenance downtime includes refueling and rearming. Repair time delays will be imposed on C- and D-type kills. The time for those B-kills that occurred in nonpenetration type missions reflects the total recovery and repair time.

4. REFERENCES:

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CHAPTER 7

MOVEMENT MODEL

1. MILITARY UNIT MOVEMENT. The DIVWAG Movement Model is designed to represent the movement of military units about the battlefield. The model accomplishes the repositioning of units by considering characteristic administrative or tactical movement rates for the type unit to be moved; the effects of barriers and facilities that may tend to impede or improve the unit's movement capability; the effects of variations in terrain, weather, and light conditions on the unit's movement capability; and the availability of fuel.

a. DSL-Ordered Movement. Tactical and administrative movement of units by ground or air in the Movement Model is usually in response to gamer-planned DSL orders. The gamer must plan, coordinate, and schedule all movement performed by this model, except that controlled by the Engineer Model.

b. Model-Ordered Movement. The Engineer Model sets up the necessary parameters and calls the Movement Model, allowing it to perform the actual relocation of an engineer unit. The Engineer Model is described in Chapter 8.

c. Automatic Movement. For the most part, movements of units not in direct response to gamer input orders are accomplished within other models of the DIVWAG system. The Ground Combat Model (Chapter 4) moves maneuver units while they are actually engaged in combat, the Combat Service Support Model (Chapter 9) controls logistic movements, and the Air Ground Engagement Model accomplishes the movement of air units when this movement is in response to automatically generated missions. The reconnaissance portion of the Intelligence and Control Model regulates movement of reconnaissance units and subunits. Treatment of these movement categories is documented with the appropriate models.

2. MODEL DESIGN:

a. General. The Movement Model is designed to represent aerial and ground movement capabilities using a four-phase process to integrate gamer planned and scheduled unit movement into dynamic unit locations within the DIVWAG system during the game period. This process is illustrated in Figure 7-1, DIVWAG Movement Model Macroflow, with the phases identified as I, II, III, and IV. Briefly, these four phases consist of the development of DSL movement orders, Phase I; the integration of these orders into model path segments, Phase II; the determination of the appropriate unit rate along these model paths, Phase III; and, finally, the performance of the unit's movement along the model segment and the update of unit location and consumption data, Phase IV. The last three phases are internally performed during the dynamic game period by the movement submodels, while the initial phase is performed external to the Movement Model as a gamer function or internal function of another model.

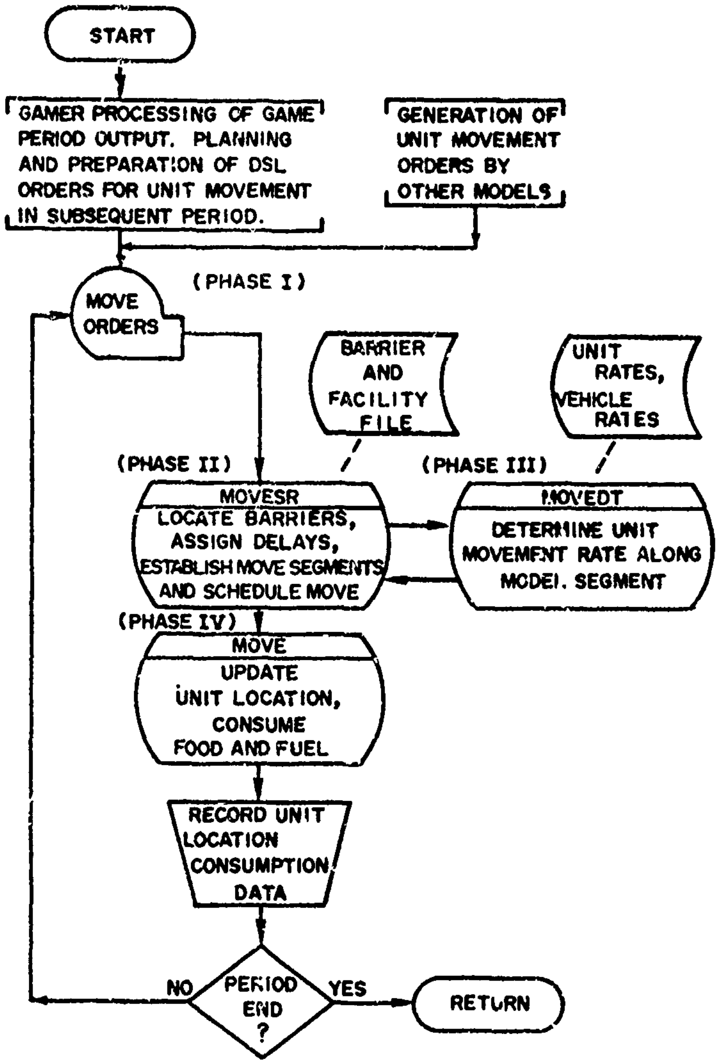

Figure 7-1. DIVWAG Movement Model Macroflow

(1) Unit Movement Planning, Phase I. Briefly, the first phase consists of the planning, coordination, and scheduling of unit movement and, in the case of gamer-ordered movements, is accomplished prior to each game period. (Planning accomplished internal to other models is documented with those models.) Phase I provides the Movement Model with movement parameters from which to generate the required unit movement. Although this first phase is external to the movement submodels representing the other three phases in the figure, it nonetheless provides the vital information necessary to generate unit movement within the model. The DSL orders pertinent to Phase I are discussed in Paragraph 2b(1).

(2) Model Move Segments and Coordination. Phase II is the model Move Segment Determination and Coordination Submodel (MOVESR) and functions to integrate the movement orders into scheduled model move segments within the DIVWAG system. This submodel breaks the total move path (order segment) down into model move segments, the endpoints of which specify the positions where the units are actually located within the model. This submodel also integrates effects of barriers and facilities on movement into the unit's movement schedule when required to do so.

(3) Unit Movement Timing. The Movement Rate Determination Submodel (MOVEDT) establishes the appropriate unit movement rates along the model's move segments. This rate, when combined with the length of the move segment, provides the time sequencing information needed to schedule the completion time of the model's movement event activity.

(4) Move Segment Completion. The performance of the move along the model segment is accomplished in the fourth phase by the Move Performance Submodel (MOVE). In this routine the unit's location in the model is updated, and the unit's consumption of food and fuel along the move segment is recorded.

b. Specific Model Design. This paragraph discusses the specific design aspects of the Movement Model applying to the overall model. It provides a summary overview of the various submodel functions. The model design is discussed with respect to four topics: DSL movement orders, model move segments, unit movement rates, and the Movement Model interfaces with other DIVWAG models.

(1) DSL Movement Orders. The gamer DSL orders that schedule the simulated ground movement in the model are MOVE, ADVANCE, and WITHDRAW. The corresponding order for air movement is the FLY order. A typical ground movement order given to a unit might be of the following form:

STAY UNTIL 0800.
MOVE TO X_1-Y_1, X_2-Y_2, X_D-Y_D BY TRGM.

The movement path schematic for the unit given such an order is illustrated in Figure 7-2. The DSL ground movement order contains the Movement Model parameters in the form of the travel mode mnemonic, TRGM; the specific type

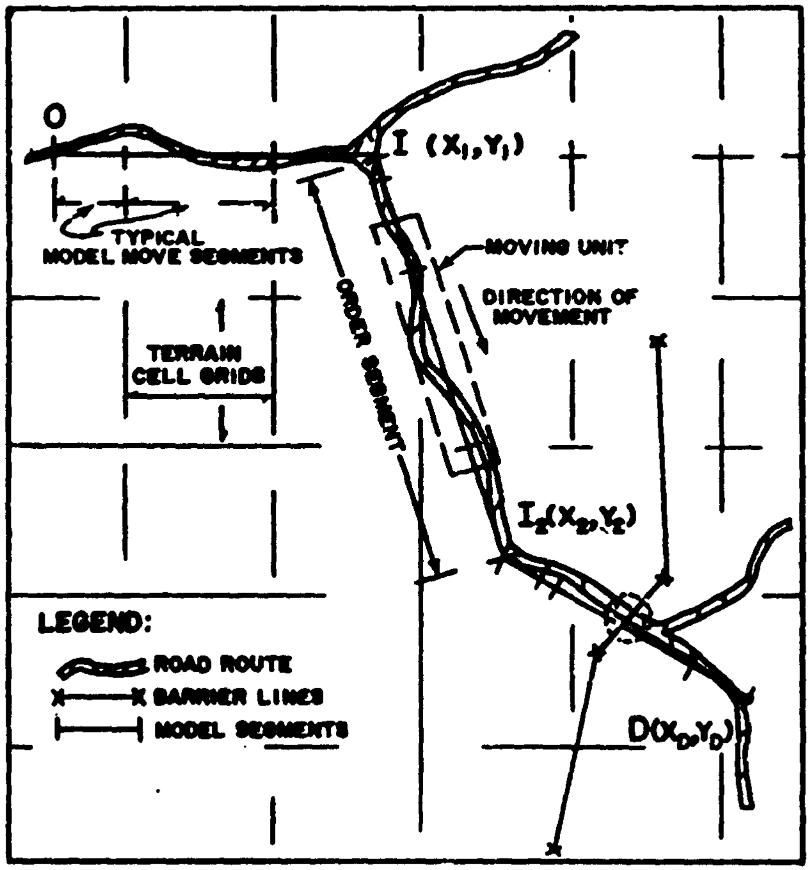

Figure 7-2. DSL Move Path Schematic

of move order, MOVE; the series of DSL path segment endpoints specifying the travel route to be followed, I_1, I_2, and D; and the scheduled time of departure, 0800, as determined by the STAY order immediately preceding the MOVE order. (Nonmovement, or remaining in position, is accomplished by the STAY and PREPARE orders for ground units and by the LOITER order for air units.)

(a) Travel Mode Mnemonic. The travel mode mnemonic contains the gamer specification of the type of unit movement desired, the route type, and the unit's formation type. The type of unit movement requested may be administrative or tactical:

A - ADMINISTRATIVE. This category implies movement of units by road nets and uses the most efficient transportation systems available with tactical considerations of secondary importance.

T - TACTICAL. Movement of this type includes cross country; movement in partially deployed, reconnaissance, or column march formations; and tactical road marches as part of an attack, withdrawal, or other tactical plan external to maneuver movement within ground combat engagements.

The route type defined in the DSL travel mode mnemonic is one of the following types:

CC - CROSS COUNTRY. Route of the unit is subject to natural terrain conditions existing in its path.

RA - PAVED ROADS. This route type is such that road beds are asphalt or concrete with at least two lanes with good shoulders, and the route is not significantly dependent upon short range or local terrain features.

RG - GRAVEL ROADS. Route is gravel or similar surfaced road with periodic maintenance.

RD - DIRT ROADS. Route is dirt, road is narrow and/or marginally maintained and is subject to terrain undulations and other local terrain features.

The unit formation is specified as column march formation, reconnaissance, or deployed, and is identified as:

M - COLUMN MARCH. The unit is in a column formation on a road or cross country route.

R - RECONNAISSANCE. Deployment pattern on cross country by a unit on a ground reconnaissance type mission.

D - DEPLOYED. Unit is partially deployed in a formation in anticipation of imminent contact with the enemy.

The letters composing the travel mode mnemonic are used in the model to identify the movement parameters applicable to the current unit movement. The first character specifies the move type, the second and third are used to indicate the route type, and the fourth is used to designate the formation type. The various combinations allowed in any particular game are defined in the pregame data preparation process. A typical group used for a game might be as follows:

ARAM - Administrative move on all-weather roads in march column formation.

ARGM - Administrative move on gravel roads in march column formation.

TRAM - Tactical move on asphalt, concrete, or similar paved road in a march column formation.

TRGM - Tactical move on improved, gravel, or similar surfaced roads in a march column formation.

TRDM - Tactical move on unpaved or dirt roads in a march column formation.

TRGR - Tactical move on improved, gravel roads in a reconnaissance type formation.

TCCM - Tactical cross country move in a march column formation.

TCCR - Tactical cross country move in a reconnaissance formation.

TCCD - Tactical cross country move in a deployed formation.

The travel mode mnemonic is discussed extensively in Volume VI, DIVWAG Data Requirements Definition, Chapter 11.

(b) Travel Route. In addition to the type of route specified for the unit's movement, the actual route to be traversed is designated in the movement order by a set of intermediate coordinates and the final objective coordinates for the move; thus, the gamer specifies the actual route to be taken by the unit as a series of line segments. These segments are referred to as order segments and are to be distinguished from the model move segments discussed later in Paragraph 2b(2). Both types of segments are illustrated on the movement schematic of Figure 7-2. If the route type specified in the travel mode mnemonic is by road, the gamer-generated order segments are to be chosen such that the straight line segments approximate road routes actually available to the unit. In the model's computation of road movements a factor of 10 percent is automatically added to the straight line distance to allow for a representation of the actual minor deviations from a straight line experienced on most roads. (This subject is discussed in the Move Rate Determination Submodel, MOVEDT.) In road movement, as well as in other unit movement, the DSL movement parameters in the DSL order must be carefully chosen to realistically represent the terrain environment of the unit as derived from a detailed map study of the travel routes designated.

(c) Unit Time of Departure. The scheduled time at which the model commences to move the unit is implied in the DSL order string. In the example, the preceding STAY order for the unit established the departure time as 0800 or, equivalently in the model, the completion time of the unit's stay activity.

(2) Model Move Segments. Within the Movement Model, dynamic relocation of a unit is accomplished in discrete model move segments. The model move segments are determined by the location of the unit with respect to endpoints of the order segment, the boundaries of terrain cells, and the locations of barriers in the path of the moving unit. Although units will always complete a model move segment, it is possible for a unit not to complete an order segment and to stop en route to the desired objective. The termination of model move segments at terrain cell boundaries allows the unit's movement rate to be adjusted to represent unit mobility response to changing terrain features. In the case of a barrier, if the unit's route will cause the unit to encounter the barrier, the endpoint of a model move segment is determined by the location of the barrier. The effect of the barrier on the unit's movement is assessed as discussed in the submodel specifications for MOVESR.

(3) Unit Movement Rates. To represent unit movement rates along the DSL ordered routes, the model requires two sets of rate tables: the Unit Type Designator (UTD) Normal Rate Tables for road and cross country movement and the Mobility Class Rate Tables for road and cross country movement. Both sets of tables are developed in the pregame data preparation phase in accordance with the procedure described in Volume VI, DIVWAG Data Requirements Definition, Chapter 11. The rates in these tables are representative rates for the various terrain, weather, and light conditions. Briefly, the mobility class rates are intended to represent short-term characteristic vehicle rates under

the specified conditions, while the UTD normal rates reflect unit movement for given situations, formations, and environmental conditions. The UTD normal rates are representative of long-term or sustained rates to be expected under the existing circumstances, representing standard or planning rates. These rates are discussed in greater detail in the submodel specifications of the Move Rate Determination Submodel, MOVEDT. Once the rate of the unit is established for the segment, it is combined with the length of the segment to compute the required time for the unit to complete the movement along the model segment. This time is then used in the event sequencing structure of the DIVWAG system to effect the timing of the dynamic performance of the move and subsequent updating of the unit location on the terrain cell grid.

(4) Movement Model Interfaces with Other Models. The Movement Model provides the Combat Service Support Model and the Ground Combat Model with rates for generating automatic movement internal to these models. It interfaces the system Environment Model, using weather, terrain, and light conditions to establish the appropriate move rates. An interface is also effected with the Area Fire/TACFIRE and Air Ground Engagement Models when casualties due to indirect or aerial fires are assessed and the unit's movement is interrupted. The detection of moving units by the Intelligence and Control Model is triggered by initiation of each move segment. The Engineer Model provides all barrier information for the Movement Model.

(a) Ground Combat Model Interface. Movement within the Ground Combat Model represents cross country ground maneuver movement in a deployed formation while in contact with the enemy. To accomplish this movement, the Ground Combat Model requires the vehicular mobility class rates used within the Movement Model. The specific use of these rates is described in Chapter 4 of this volume. The Movement Model initiates a ground combat engagement when an advancing attacker comes within range of an opposing unit, which has been predesignated within a DSL battle scenario.

(b) Combat Service Support Model Interface. To develop resupply schedules and to represent the movement of logistical vehicles, the Combat Service Support Model accesses the vehicular movement rate tables provided in the Movement Model. Details are specified in Chapter 9 of this volume.

(c) Environment Model Interface. To determine rates representative of environmental conditions the Movement Model uses weather, terrain, and light conditions supplied by the Environment Models to locate the correct rates in the movement rate tables. The rate tables are prepared pregame and include consideration of all possible environmental conditions that might be encountered during the game period. The specific parameters and their use are described in detail in the submodel specification of MOVEDT.

(d) Engineer Model Interface. A subroutine of the Engineer Model is interrogated to determine if a move segment intersects a barrier line. If it does, the Engineer Model also provides other information about

the barrier, which may allow the unit to be routed around the barrier or to an existing facility. If such rerouting is not feasible, the information is used to decide whether to force the barrier or to request the Engineer Model to construct a facility (breach or bridge) at that point.

(e) Nuclear Assessment Model Interface. Craters and radiation resulting from nuclear detonations serve as barriers to unit mobility. If the Movement Model is informed that a unit's move segment will intersect a nuclear barrier, additional information is obtained from the Nuclear Assessment Model. This information allows the Movement Model to determine if the unit should bypass the barrier or cross the barrier and accept the radiation.

(f) Area Fire/TACFIRE Model and Air Ground Engagement Model interfaces Target coverage calculations within the Area Fire/TACFIRE Model are synchronized with Movement Model move segment determination so that the location of a moving unit at the time of impact is correctly projected for use in assessing the effects of each area fire volley. Details of the target coverage calculation are contained in Chapter 5. Both the Area Fire/TACFIRE and Air Ground Engagement Models set up an activity suppression event that causes a unit's movement to be interrupted when it receives fire. A detailed explanation of the modeling of suppression is contained in Chapter 5.

(g) Intelligence and Control Model Interface. The movement event scheduling routine calls the conditional collection of moving targets routine to determine if any stationary sensor is in a position to detect the moving unit during the current model move segment.

3. SUBMODEL SPECIFICATIONS:

a. General. Each of the three movement submodels is discussed in the following subparagraphs. Together, they represent the Movement Model's response to gamer orders. The model Move Segment Determination and Coordination Submodel (MOVESR) interfaces unit movement activity into the DIVWAG system consistent with other unit military activities represented by other models. The Movement Rate Determination Submodel (MOVEDT) establishes typical unit rates and provides the MOVESR Submodel with time sequencing information for the proper coordination of unit movement events. Each arrival at the endpoint of a model move segment is scheduled as a movement event. Actions performed by the MOVE Submodel consist of updating the unit's location and consumables, particularly fuel, when the arrival at a model move segment is scheduled. The submodels are described in the sequence in which they operate in the system.

b. Model Move Segment Determination and Coordination. The macroflow of MOVESR is shown in Figure 7-3. Based on the pending movement order, the endpoint of the next model move segment is determined and, in conjunction with the Move Rate Determination Submodel (MOVEDT), the projected time of unit arrival at that endpoint is calculated. The actual move event, which is

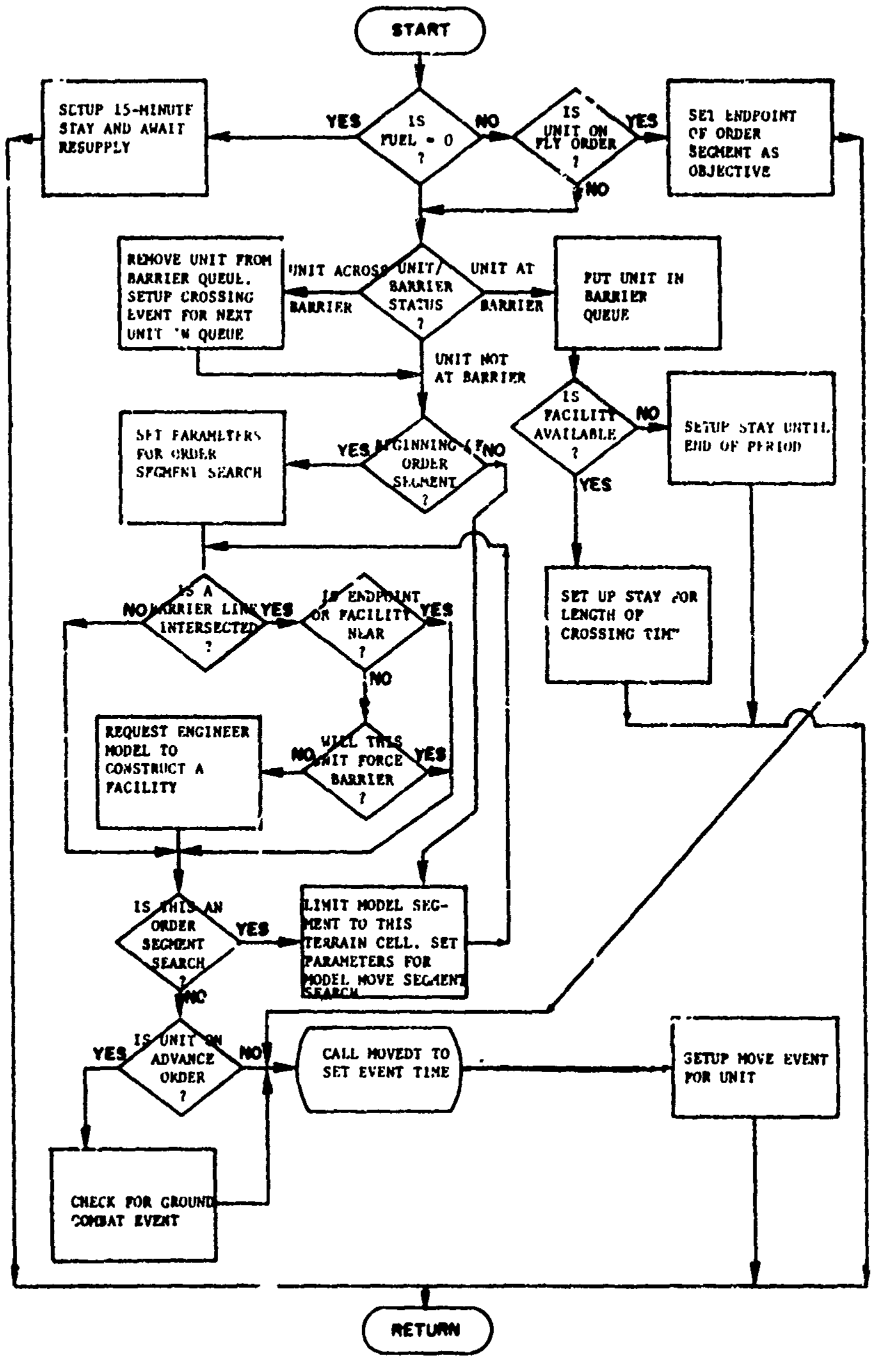

Figure 7-3. MOVESR Macroflow

arrival at this endpoint, is then entered into the DIVWAG event sequencing logic, as discussed in Chapter 1.

(1) Ground Movement. The model move segments of a ground movement will have their endpoints at the endpoints of order segments, at terrain cell boundaries, or at barriers. The concept is illustrated in Figure 7-2 where 13 model move segment endpoints are generated; three for the order segments, one for the barrier, and nine for terrain cell boundaries. One cycle through each routine is generally required for each model move segment. As each move event (arrival at an endpoint) is completed, MOVESR is called to find the next model move segment's endpoint, and MOVEDT is called to schedule arrival time at that point.

(2) Air Movement. Since terrain characteristics or ground obstacles do not affect air movement, the model move segment endpoints are those of the DSL move segments for air movement. The DSL FLY order specifies a flight speed, which is used to schedule arrival of the unit at move segment endpoints.

(3) Movement Delays:

(a) MOVESR will automatically schedule a movement delay if a unit is out of fuel by generation of a stay event of 15 minutes duration for the unit. Additional 15-minute stays are assessed until the unit is resupplied with fuel. This procedure will cause a unit to cease movement when fuel is exhausted and to remain immobile (STAY) until its fuel is replenished by the Combat Service Support Model. When the unit once more has fuel, its movement is continued along the ordered route.

(b) A unit may be delayed by barriers as described in subparagraph (4), below.

(4) Effects of Barriers and Facilities:

(a) As a unit begins its movement along an ordered move segment, a search, using force intelligence information, is made to determine if that segment intersects a barrier line (e.g., river, minefield, forest). If it does, the unit will be routed around the end of the barrier line or to an existing facility, if either is sufficiently close. The current criterion for nearness is one-half the sum of the unit's width and depth. If neither an end of the barrier or a facility is near, the unit will continue its movement to the point of intersection.

(b) If the barrier may be forced (e.g., minefield), a decision table is interrogated to determine if the unit should force or should request engineering action and wait for a facility to be constructed. The force/no force decision is a function of the time required to breach the barrier, the casualties that would be assessed if it is forced, and the priority of the move. This decision table is part of the pregame constant data.

(c) If the barrier cannot be forced (e.g., a river), or the decision is not to force, the Engineer Model is requested to provide a facility at the point of intersection. This request is made at the time the barrier is discovered to be in the unit's path. When the unit arrives at the site of construction, it is given a STAY order and will remain in the STAY mode until the facility is complete or the period ends.

(d) As the Movement Model prepares to move the unit along each model move segment, a second search for barriers is made along that portion of the movement path with actual barrier information being used. This allows the effects of barriers and facilities unknown to the unit's force intelligence to be modeled. If an intersection with an active barrier (e.g., minefield or nuclear radiation) is found, casualties will be assessed the unit discovering the barrier. Then the logic described in Subparagraph (4)(a),(4)(b), and (4)(c) is employed again to determine the unit's course of action.

(e) Unless the facility provided is a bridge constructed as part of a roadway and the unit is marching on that road, passing through the facility will temporarily disrupt the formation of the unit and will cause lost time. The Engineer Model provides a crossing rate in terms of vehicles per minute. This rate and a count of the vehicles in the unit allow the time lost to be calculated.

(f) It is possible that a unit will request the use of a facility while it is already in use or while it is under construction and other units are waiting for its completion. If this situation occurs, the unit will be placed in a wait queue. If the unit has decided to force the barrier and no engineer activity has begun, it will be placed first in the queue and be allowed to force immediately. Otherwise, the unit will be positioned in queue by priority and, within priority, on a first in, first out basis.

(5) Advance to Ground Combat Engagement. If a move is ordered by a DSL ADVANCE order, MOVESR coordinates the initiation of the designated battle. A sample ADVANCE order string is:

ADVANCE TO 1162000 - 0910000.
ENGAGE IN BATTLE FOXTROT.

MOVESR continues to move the unit toward the objective point in 300-meter move segments. Each segment is checked to determine if the unit will come within 3000 meters of an opposing unit listed in the scenario of Battle FOXTROT. Upon reaching that point, the unit is automatically released from the Movement Model and is turned over to the Ground Combat Model by converting the order from ADVANCE to ENGAGE. If a unit listed in a battle scenario is given a DSL WITHDRAW order, it is also moved in 300-meter segments and automatically released to the Ground Combat Model when the battle is initiated.

c. Movement Rate Determination Submodel (MOVEDT). Unit movement rates are established in the submodel MOVEDT. A macroflow of this submodel is illustrated in Figure 7-4, and a schematic of the rate selection process is shown in Figure 7-5. The rates available to the model are established in the pregame data preparation phase as illustrated in the lower left and right corners of Figure 7-5. The unit's movement rate is established by identifying the nature of the move from the travel mode mnemonic and by the prevailing environmental conditions. Using these parameters the appropriate unit movement rate tables and the mobility class short-term rate tables are obtained. The unit is checked to ascertain its present composition in terms of vehicular mobility classes and is not allowed to exceed the maximum rate at which its component vehicles can move. If a delay is encountered on a tactical move, the unit is allowed to exceed its standard movement rate in an attempt to make up for lost time. The rate used is that of the unit's slowest vehicle not in an excluded mobility class. Exclusion of mobility classes is discussed in subparagraph (2)(c), below. Thus, a unit executing a tactical move is able to draw from a reserve mobility capability, if it exists, along each order segment when required to do so by dynamic events causing delays for the unit.

(1) Environmental Parameters. The Movement Model uses selected environmental parameters as listed below. (A detailed discussion of the Environment Model used within DIVWAG is contained in Chapter 2.)

(a) Road Terrain Factors. The roughness and vegetation index of the Terrain Model is used to specify two road terrain factors for each terrain cell: terrain I, flat, gently rolling to undulating (roughness and vegetation index equals 1 to 5); and terrain II, undulating, broken to rough (roughness and vegetation index equals 6 to 9).

(b) Day and Night. Times from Beginning of Morning Nautical Twilight (BMNT) to End of Evening Nautical Twilight (EENT) are considered daylight, and times from EENT to BMNT are considered night.

(c) Weather. The weather factors considered in the model are precipitation; none, light, or heavy; and fog. The model is designed to require data for only typical summer or typical winter conditions during a single game. It is expected that input data for summer and winter would differ significantly. The model assumes fog has the same effect as heavy precipitation upon unit movement.

(d) Cross Country Terrain Factors. Cross country movement rates may be specified for up to 20 terrain trafficability indices as described in Chapter 2.

(2) Movement Rate Data. Three basic groups of data are used by the Movement Rate Determination Submodel: unit mobility category movement rates, equipment mobility class movement rates, and equipment mobility class exclusion tables.

(a) Unit Mobility Category Movement Rates. In the pregame data preparation process, type units are grouped together into unit mobility

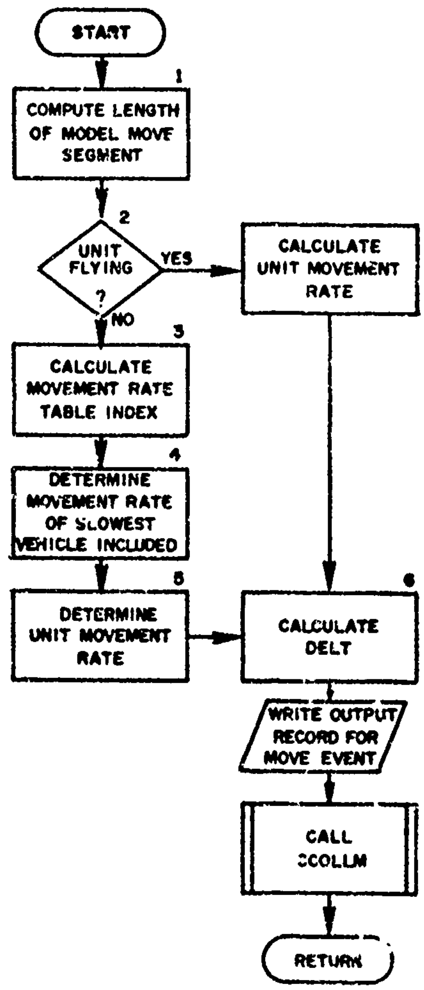

Figure 7-4. MOVEDT Macroflow

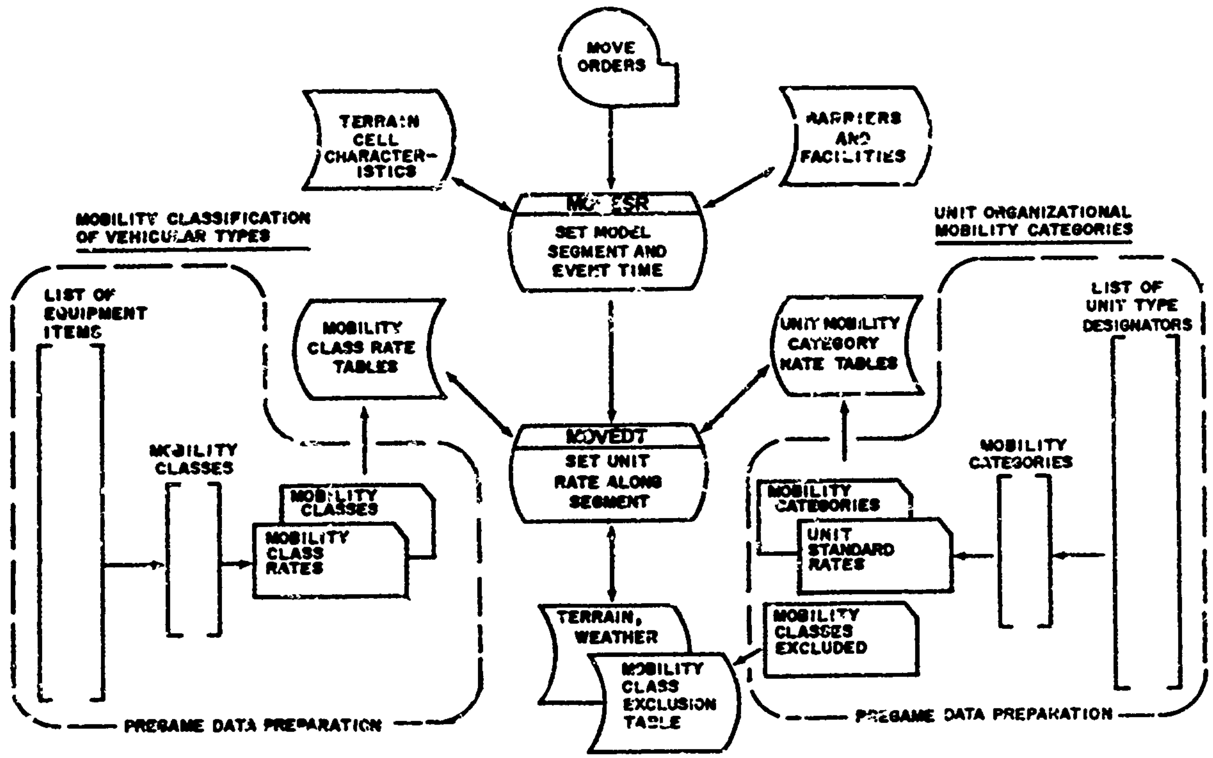

Figure 7-5. Movement Rate Determination Schematic

categories. A unit mobility category is a group of type units, all of which will move at similar unit movement rates under similar conditions. For each unit mobility category, a set of unit movement rates must be contained in the data base. These are the rates at which units in the specified mobility category will normally move in each type of movement to be defined by a movement mode mnemonic [see Paragraph 2b(1)(a)] under the set of environmental conditions treated by the model. Infantry and tank mobility categories must always be defined, as the movement rates for these categories are defaulted to under the conditions discussed in subparagraph (3)(d), below.

(b) Equipment Mobility Class Movement Rates. In pregame data preparation, all ground mobility items to be played in a game are assigned to mobility classes, which group together items assumed to have similar mobility characteristics and, thus, similar movement rates. A maximum of 20 mobility classes may be defined for each force, with the first class reserved for foot movement. For each mobility class, a set of movement rates is required, which is representative of maximum rates achievable for short-term movement (short-term catch-up rates). These rates are required for road and cross country movement under the set of environmental conditions dealt with in the model.

(c) Mobility Class Exclusion Tables. To allow for situations in which certain of the unit's mobility items should not be allowed to limit the unit's rate of movement (e.g., reconnaissance movement in which organic logistic vehicles would not normally be used), the mobility class exclusion tables identify for given unit mobility categories and travel modes the equipment mobility classes not allowed to limit unit movement. The foot class is used only as a default rate and need not be excluded.

(3) Movement Rate Determination. The rate at which a unit moves is determined by the travel mode mnemonic of the DSL order, environmental conditions at the time of the move, and the movement rate data. Generally, the travel mode mnemonic, the unit's mobility category, and environmental conditions are used to determine the unit mobility category movement rate that applies. Items organic to the unit at the time of the move are checked, via the equipment mobility class movement rate data, to ensure that the unit rate does not exceed equipment capability. The mobility class exclusion table may, however, override this check.

(a) Administrative Ground Movement. All DSL orders that specify administrative movement use the standard unit mobility category rates with the mobility class constraints applied as described above. The unit's actual rate of movement, R_A, is always the minimum of the unit mobility category rate, R_N, and the limiting equipment mobility class rate, R_{MC}; i.e.,

$$R_A = \text{MINIMUM } (R_N, R_{MC}) \qquad (7\text{-}1)$$

(b) Tactical Ground Movement. When the DSL order identifies the unit's movement type as tactical, the determination of the unit's actual movement rates requires an additional check on the status of the unit's movement along the entire DSL segment. The status is parameterized by the time delays resulting in unit movement delays that have occurred during this DSL segment. If the unit is not operating under a time delay, the movement rate, R_A, is established by Equation 7-1. If, however, the unit has been delayed, it is allowed to move at the limiting mobility class rate (assuming that rate exceeds the unit mobility category rate). The time behind schedule or model delay parameter, δT_L, is determined from three sources; i.e., the obstacle delays in MOVESR, the mobility class limits of the MOVEDT Submodel, and movement interruption caused by enemy fire.

1. If a unit encounters an enemy obstacle, MOVESR updates the delay parameter by adding a representative delay time, δT_{delay}, to the time behind schedule as:

$$\delta T_L(\text{new}) = \delta T_L(\text{old}) + \delta T_{delay} \qquad (7\text{-}2)$$

When the unit reaches the endpoint of a DSL segment, δT_L is reset to zero, thus providing a representation of the nonsustainability of the short-term catch-up rates.

2. The delay parameter is also adjusted whenever a unit in a tactical move effectively falls behind schedule because of limiting mobility class characteristics. The actual time delay is adjusted as:

$$\delta T_L(\text{new}) = \delta T_L(\text{old}) + d_{ss}\left(\frac{1}{R_A} - \frac{1}{R_N}\right) \qquad (7\text{-}3)$$

where:

d_{ss} = subsegment length of the current tactical movement by a cross country route

d_{ss} = (1.1) x (subsegment length) if the route is a road type.

3. The delay caused by enemy fire is set by the Suppression Submodel.

(c) Road Planning Factor. In road movement for both tactical and administrative moves the actual model movement rate along the model move subsegment is adjusted to represent the actual road route involved. The rate tables specify the actual road rates, but since the DSL segments are straight

line segments, the model rates along these segments need to be adjusted to represent actual road movement. For road movement a 10 percent road planning allowance factor is used to give an adjusted model rate, R_M,

$$R_M = \frac{R_A}{1.1} \tag{7-4}$$

and the delay parameter, δT_L, in Equation 7-3 as indicated. The road movement logic requires the DSL gamer-ordered road movement to be planned with the 10 percent road allowance factor in mind to represent realistic road movement rates.

(d) Default Rates. If the move combination specified in the order has not been defined in the pregame requirements table of travel mode mnemonics versus mobility categories, a default to the dismounted personnel rate is used. If the DSL-ordered travel mode mnemonic is invalid, TCCD is used. If the movement rate table required by a particular combination is undefined, the movement rate of heavy tracked vehicles (tanks) is used.

(e) Move Event Time. The time, ΔT, to complete the move model subsegment is computed in MOVEDT as:

$$\Delta T = \frac{d_{ss}}{R_M} \text{ or } \frac{d_{ss}}{R_A} \tag{7-5}$$

as appropriate and is used to set the move event time in MOVESR. This time is the only parameter returned by the MOVEDT subroutine.

d. Movement Execution Submodel. The movement event scheduled in MOVESR is actually performed in the submodel MOVE. This submodel updates the unit's actual coordinate location to the endpoint of the model move segment and accounts for consumption of Class III or Class IIIA and food. A macroflow of the MOVE subroutine is illustrated in Figure 7-6.

(1) For moving units, the total POL consumption is determined by:

$$C_s = \sum_{i=1}^{M} r_{cs_i} \cdot D \cdot N_{E_i} \tag{7-6}$$

for equipment types having distance-dependent consumption rates, and by:

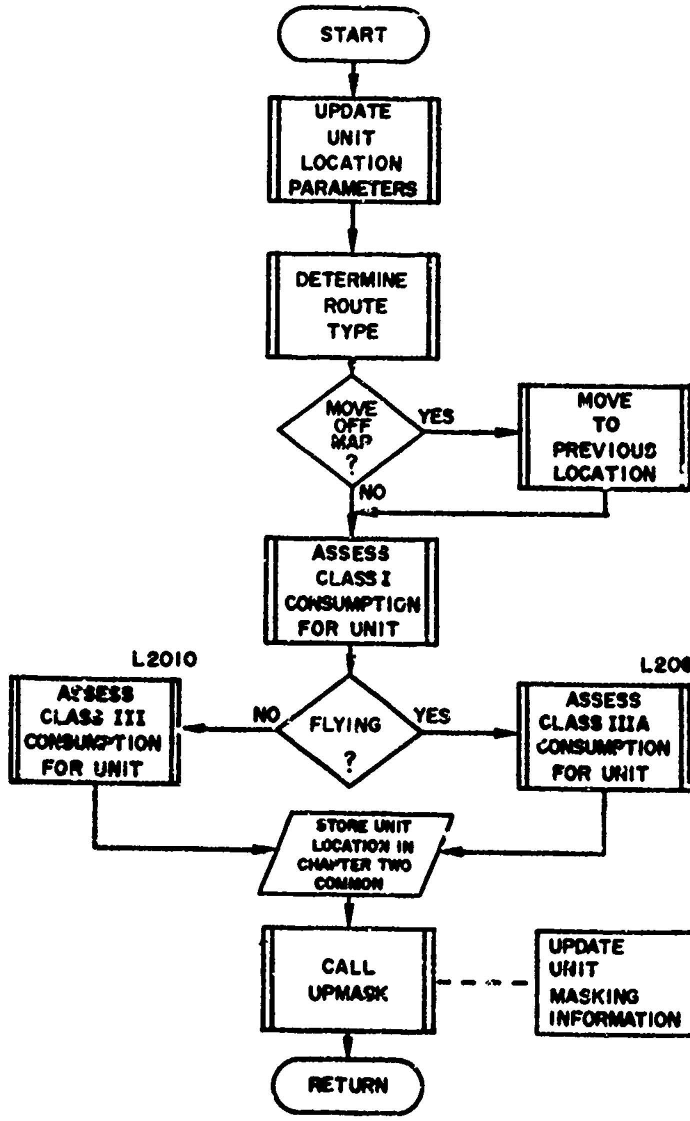

Figure 7-6. MOVE Macroflow

$$C_t = \sum_{j=1}^{N} r_{ct_j} \cdot \Delta t \cdot N_{E_j} \quad (7\text{-}7)$$

for equipment types having time-dependent consumption rates, where:

C_s = amount of fuel (gallons) consumed by distance-dependent vehicles

C_t = amount of fuel (gallons) consumed by time-dependent vehicles

M = number of distance-dependent vehicle types in unit

N = number of time-dependent vehicle types in unit

r_{cs_i} = fuel consumption rate (gallons/meter/vehicle) for distance-dependent vehicle i

r_{ct_j} = fuel consumption rate (gallons/meter/vehicle) for time-dependent vehicle j

D = length (meters) of subsegment

Δt = time (minutes) increment

N_E = number of distinct items of equipment for a given item code.

(2) Fuel consumption for stationary units (e.g., idling engines, generators) is determined in much the same manner except that all vehicles have time-dependent fuel consumption rates. The calculation is as follows:

$$C_t = \sum_{j-1}^{MN} r_{ct_j} \cdot \Delta t \cdot N_{E_j} \quad (7\text{-}8)$$

where:

C_t, r_{ct}, Δt and N_E are as previously defined, and

MN = total number of vehicle types in the unit.

(3) Consumption of food is recorded continuously for all simulated activities within the DIVWAG system. The food available to a unit must be carried within the unit's own supplies. The rate of consumption is specified for a force in terms of pounds per man per day, but this value is converted

to pounds per man per minute at the time of execution. This consumption value is determined by:

$$C_f = (G + B) \cdot r_{cf} \cdot \Delta t \qquad (7\text{-}9)$$

where:

C_f = amount (pounds) of food consumed

G = suppressed (combat ineffective) personnel in the unit

B = present effective personnel in the unit

r_{cf} = food consumption rate (pounds/man/minute)

Δt = time (minutes) increment of event.

CHAPTER 8

ENGINEER MODEL

1. MILITARY ACTIVITY REPRESENTED:

a. General. The Engineer Model represents combat engineer activities in support of a division in combat.

b. Engineer Missions. The generalized missions of the division engineer battalion are:

- To increase the combat effectiveness of the division by means of engineer combat support.

- To carry out an infantry combat mission when required.

The Engineer Model addresses only the first mission.

c. Engineer Functions. Functions performed by the division engineer battalion to carry out the engineer combat support mission fall into two broad categories, which may be called hard support functions and soft support functions.

(1) Hard Support Functions. These functions have the objective of facilitating or enhancing friendly force mobility and impeding or degrading hostile force mobility; they include such activities as breaching of minefields and bridging of gaps.

(2) Soft Support Functions. These functions influence combat power only indirectly; they include such activities as supply of potable water, provision of technical advice, and supply of locally available construction materials.

d. Model Constraints and Capabilities. The Engineer Model is limited to portrayal of those hard support functions related to the mobility element of combat power.

(1) The model is capable of simulating three types of functions or activities:

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(a) BUILD. The BUILD function is defined as the construction of a new barrier or facility.[1] It also includes maintenance or improvement of an existing barrier or facility and repair or rebuilding of a breached barrier or facility.

(b) BREACH. The BREACH activity is defined as the disruption of the functional mission of a barrier or facility. To BREACH a barrier is to clear a passageway through or across the barrier. To BREACH a bridge is to disrupt its function as a facility. (A bridge is a facility because it provides a passageway across a stream or gap or other form of barrier.) To BREACH implies functional disruption only and does not imply total elimination; the latter is covered by the REMOVE activity.

(c) REMOVE. The REMOVE function is defined as the 100 percent clearance or neutralization of a barrier or facility. Removal as played by the model is only of a destructive nature. Destructive removal implies total destruction rendering the facility useless for reconstruction or reuse.

(2) Engineer tasks in the model are limited to minefields, fords, bridges, and rafts/ferries. The combinations of task activities and facilities on which they may be performed are shown in Figure 8-1.

Facility	Task Function/Activity		
	Build	Breach	Remove
Minefield	X	X	X
Ford	X	X	
Bridge	X	X	X
Raft/Ferry	X		X

Figure 8-1. Engineer Task Activities

1. A barrier is defined as any feature, natural or man-made, which tends to reduce the mobility of military forces. A facility is defined as any feature, natural or man-made, which tends to reduce the effect of a barrier (e.g., defiles or passes in a ridge line), or to neutralize or negate the barrier (e.g., roads, bridges, and fords).

2. MODEL DESIGN:

a. General. The Engineer Model simulates the scheduling and execution of engineer tasks and assesses delays incident to the tasks and the related barriers and facilities. The model accepts engineer tasks, assigns priorities to them, determines task feasibility, assigns resources according to task priority, mobilizes task forces, executes the tasks, reports results, demobilizes the task forces, and maintains current status information on barriers and facilities.

(1) Task Basis. Engineer tasks are based upon pregame gamer-prepared barrier plans and controller-prepared barrier guidance. Such plans and guidance are updated as required at the beginning of each game period.

(2) Task Initiation:

(a) Engineer tasks may be initiated by either of two methods:

1. Gamer DSL orders issued at the beginning of a game period.

2. Automatic orders generated during a game period by the Movement Model when a unit in movement encounters a barrier.

(b) Although it is not strictly an engineer task initiation, the Engineer Model is also triggered automatically by the Nuclear Assessment Model when a nuclear event results in the creation of a barrier or affects the status of an existing barrier or facility.

(3) Task Priority Assignment. The allocation and scheduling of resources for engineer tasks is based upon model assignment of a 3-digit task priority indicator. One of the indicator digits is fixed and is based upon pre-set game rules; the other two digits are variable and partially gamer-controlled.

(4) Task Feasibility. Based upon assigned priority, each task is checked for feasibility in two areas: resources and manpower. Resource and manpower feasibility are determined from a comparison of resources/manpower required (pre-established data base specifications) and resources/manpower available.

(5) Resource Allocation. When a task has been passed for feasibility, resources are allocated or committed, and expendable equipment and supplies are reordered.

(6) Task Force Mobilization. An available engineer troop unit is selected, required equipments and supplies are added to the unit, and the unit is moved to the task site.

(7) Task Execution. When sufficient resources are on site, engineer task work is started and delay times are calculated; when the task has been completed, work is stopped, barrier/facility files are updated, and, if other models are directly concerned with task completion, those models are notified of the completion results.

(8) Task Force Demobilization. Upon completion of the engineer task, the engineer troop unit, together with residual task equipment and supplies, is returned to its parent unit, if possible; otherwise, it is placed in a stay mode at a suitable location. If the unit is returned to its parent unit, residual equipment is then returned to the source unit from which it was originally extracted.

b. Design Philosophy. The Engineer Model has been designed on the basis of integrated performance of functions which can be described best in terms of its six functional components:

(1) An executive routine (ENGR), which provides a means for entering the Engineer Model, guides the action into the proper subelement of the model, diverts engineer resources that arrive at the task site after task termination, and handles miscellaneous tasks related to game period termination.

(2) A priority routine (EPRIOR), which assigns task priority to each engineer task, maintains a dynamic ordered list of task priorities for each force (Red and Blue), calculates the required starting time for each task, calculates task execution (including delays) and the resultant task completion time, passes task priorities to the feasibility and update routines, and advises the release routine of reasons for termination of engineer tasks.

(3) A feasibility routine (EFEASI), which determines the feasibility of performing an engineer task as a function of task priority, proximity to the FEBA, and resources and time available; commits available resources to feasible tasks in order of priority; and generates movement orders for troop units allocated to the engineer tasks.

(4) An update routine (EUPDAT), which sets a task-in-process flag when resources at the task site are sufficient for starting work, provides resource update information for task units, updates manpower on a task site and mobilizes more manpower if the current amount is inadequate for the task, calculates task performance rates and the related portion of the task completed each clock period, enters updated task information in the Barrier-Facility File, advises the release routine of each task completion, and triggers the release of engineer forces upon completion of each task.

(5) A release routine (ERELEA), which upon completion or termination of an engineer task effects the demobilization of engineer resources, including the generation of movement orders; notifies the Movement Model of completion or termination of tasks requested by that model; updates the facility status in the Barrier-Facility File; and provides period status for

end-of-period Barrier Report. This routine also precludes re-initiation of a completed task.

(6) A nuclear routine (ENUCLE), which handles the engineer aspects of radiological barriers created by nuclear events, and nuclear effects damage to existing barriers/facilities.

c. Engineer Model Interfaces with Other Models. The Engineer Model interfaces with the Movement Model and the Nuclear Assessment Model. It also makes use of various elements of the general model and, in particular, the environmental characteristics of the battle area.

(1) Interface with Movement Model:

(a) General. Since the objective of barriers/facilities is to influence the mobility of troop units, an interface between the Engineer Model and the Movement Model is essential. Through this interface, the Movement Model interrogates the Engineer Model to determine if a mobility move segment intersects a barrier line. If it does, the Engineer Model provides additional information about the barrier line to permit the Movement Model to make one of the following choices:

1. To reroute the movement around the barrier segment if feasible.

2. To reroute the movement to an existing facility if feasible.

3. To force the barrier if it is an active type.

4. To request the Engineer Model to neutralize the barrier by building a facility or by breaching the barrier at the point of intersection.

(b) Interface Subroutine:

1. When a unit starts to move along an order segment, the Movement Model requests the Engineer Model to check the segment for barriers (segment look-ahead procedure). Based on intelligence status information only the Engineer Model examines the order segment starting from the near end and continuing until a barrier is found or until the destination end is reached. If a barrier is found, the examination is terminated and the Engineer Model provides the necessary barrier information to the Movement Model. The Movement Model then makes its decision, continues the unit movement along the new route or along the original route toward the barrier, and requests the Engineer Model for an engineer task if appropriate. (In the case of rerouting, the new routing is used for further checking purposes.) If no barrier is found, the Movement Model continues the unit movement toward the destination end of the order segment.

2. Each time the moving unit enters a new terrain cell, the Movement Model requests the Engineer Model to check the cell for barriers (cell look-ahead procedure). Based on physical status information only, the Engineer Model examines that cell portion of the move segment starting from the entry point and continuing until a barrier is found or until the exit point is reached. If a barrier is found, the procedure in the previous subparagraph is followed. If no barrier is found, the Movement Model continues the unit movement to the exit point of the terrain cell.

3. When a barrier is found and rerouting is not feasible, the Movement Model continues the unit movement to the point of intersection with the barrier. There, the unit either executes forcing action on the barrier and continues movement, or it goes into a STAY mode until receipt of further orders or advice from the Engineer Model that the engineer task is completed. If the Engineer Model is unable to accomplish the task and the unit lacks conditional orders, the unit will remain in a STAY mode until the end of the game period.

(2) Interface with Nuclear Assessment Model:

(a) General. Two major factors requiring interface between the Engineer Model and the Nuclear Assessment Model are the following:

1. The employment of nuclear weapons creates radiological barriers; for economy in modeling, it is preferable that all barriers be handled in a single model (in this case, the Engineer Model).

2. Nuclear effects may easily damage or otherwise modify existing barriers/facilities. Barriers/facilities must be updated as required to reflect their current status.

(b) Handling of Radiological Barriers:

1. When a nuclear event creates a radiological barrier, the Nuclear Assessment Model advises the Engineer Model that a nuclear event has occurred, identifies the coordinates of ground zero, and specifies the radius of the effective circular radiological barrier. The Engineer Model then establishes two barrier segments tangent to the circular barrier and perpendicular to the initial slope of the battlefield.[2] Two other barrier segments are then added connecting the endpoints of the first two and forming a square to encompass the barrier. Each barrier segment is centered on its point of tangency and is of a length equal to twice the radius of the radiological barrier.[3]

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2. Determined by a line connecting the center of mass of the Blue force with the center of mass of the Red force (see Chapter 2).

3. This length was selected as an arbitrary starting point. Future operational sensitivity tests should be conducted to determine the proper magnitude.

2. When the Movement Model encounters a barrier, it requests information from the Engineer Model; if the barrier is a radiological barrier, the Engineer Model so advises the Movement Model and indicates the extent of the barrier encountered. The Movement Model then requests information from the Nuclear Assessment Model and is advised of the radiation dose that will be assessed if the troop unit is moved through the radiological barrier. The Movement Model then decides either to go through and accept the assessment or to bypass the barrier if conditions so permit.

3. At specified periodic intervals the Nuclear Assessment Model advises the Engineer Model of the decay-reduced radius of the radiological barrier, and the Engineer Model updates the location and extent of the barrier segments. When the decayed radius of the radiological barrier is less than 50 meters, the barrier will be considered of negligible effect and will be removed.[4]

(c) Handling of Nuclear Effects Damage to Existing Barriers/ Facilities:

1. When a nuclear event occurs, the Nuclear Assessment Model advises the Engineer Model, identifies the coordinates of ground zero, and specifies the maximum radius of effects pertinent to existing barriers/ facilities. The Engineer Model checks the location of existing barriers/ facilities with respect to the radius of effects and identifies those lying partially or wholly within this radius. The Engineer Model then identifies these existing barriers/facilities to the Nuclear Assessment Model, including type and endpoint coordinates.

2. The Nuclear Assessment Model considers each reported barrier/facility, assesses damage, and advises the Engineer Model as to the revised status of each such barrier/facility. The Engineer Model records the damaged barriers/facilities and the revised status of each. At the end of the game period, these data are output with barrier/facility records for report purposes.

3. Gamers examine the damage list and update the status of these barriers/facilities, as follows. If the character identification of a barrier has been changed; e.g., a forest changed to a forest fire or to tree blowdown, the gamer replaces the original barrier identification with a new mnemonic to indicate the new character of the barrier. If only a portion of a barrier has changed character, the gamer divides the original barrier segment into two or more segments to fit the new status and defines these new segments.

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4. Fifty meters was selected as an arbitrary starting point. Future operational sensitivity tests should be conducted to determine the proper magnitude.

(3) Interface with Environmental Characteristics. The Engineer Model interfaces with the following characteristics of the environment.

(a) Terrain:

1. The Engineer Model uses the trafficability indices to determine rate modifiers to be applied to engineer task performance rates to account for degradation due to variability of terrain at task sites.

2. The Engineer Model supplements the basic terrain model by permitting identification of terrain features, forestation, and man-made facilities which significantly hinder or facilitate force mobility in the context of barriers and facilities. The gamer can integrate natural features having appreciable effect on mobility (e.g., mountains, dense forests, unfordable streams) into barrier lines of significant extent. Barriers may be breached by facilities through engineer tasks. For example, a river barrier segment may be breached by constructing a bridge, a raft/ferry, or possibly a ford. Barrier segments which are unsuitable for construction of facilities are designated as unbreachable; e.g., cliffs and rivers through marshlands or those with steep rocky banks.

(b) Light Condition. The Engineer Model considers light effects and uses day/night conditions to determine a rate modifier to be applied to engineer task performance rates to account for degradation due to night conditions.

3. SUBMODEL SPECIFICATIONS:

a. General. This paragraph examines each of the major routines of the Engineer Model and presents the related logical flow, generally at the first level of detail, but at lower levels if required for clarity. Two general files are created by the Engineer Model and used by various routines in processing engineer task requests and tasks.

(1) Barrier-Facility File. The Barrier-Facility File provides the data base for engineer operations as well as working information for the Engineer Model routines. In addition, it provides an information base for other models and for reports required by the total model. A barrier or facility is described in the file in terms of its sequential location in the barrier line (previous and following segments), coordinates of its two end-points, a mnemonic identifying its type and its unique number within that type, its size if not a minefield, its density if a minefield, whether or not it is radioactive or has been damaged as the result of a nuclear event, its task-related requirements parameters, and its task status parameters.

(2) Unit Equipment File. The Unit Equipment File serves as a holding file for sources of equipments used on engineer tasks. It provides a means for returning equipment to sources when a task is completed or terminated.

b. Engineer Driver Routine (ENGR)(Figure 8-2):

(1) Purpose. The driver routine serves as access to the Engineer Model; it performs the following specific functions:

(a) Guides the action into the proper subelement of the model.

(b) Checks terminated tasks and intercepts and diverts troop units which are en route to the task site at the time the task is terminated.

(c) Handles miscellaneous tasks related to game period termination.

(2) Relation to Other Major Components. See Figure 8-2.

(a) Inputs Received:

1. From gamers: DSL orders.

2. From Movement Model: Requests for engineer tasks.

3. From Nuclear Assessment Model: Barrier information related to nuclear events.

4. From EFEASI: Engineer operating instruction.

(b) Outputs Produced:

1. For EPRIOR: Unordered task and priority list.

2. For ENUCLE: Indication of type action required.

(3) Accessories. The driver routine uses File 12 as a means for breaking down DSL orders and other communications, both external and internal, into elements that can be handled by the model.

c. Engineer Priority Routine (EPRIOR) (Figure 8-3):

(1) Purpose. The priority routine functions as the first stage of the task filter by computing the priority of all scheduled and unscheduled tasks and integrating these into an ordered priority list. It performs the following specific functions:

(a) Assigns a task priority to each engineer task.

(b) Maintains a dynamic list of task priorities for each force (Blue and Red).

(c) Calculates the required starting time for each task.

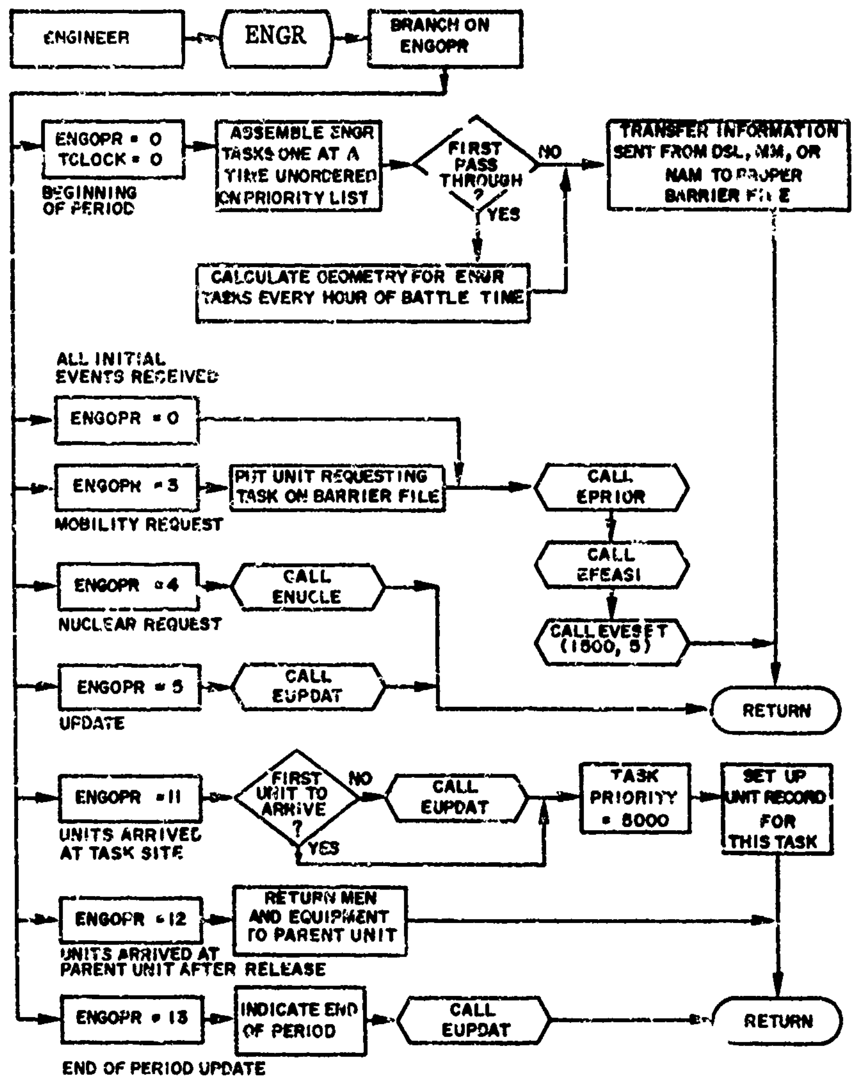

Figure 8-2. Engineer Driver Routine (ENGR)

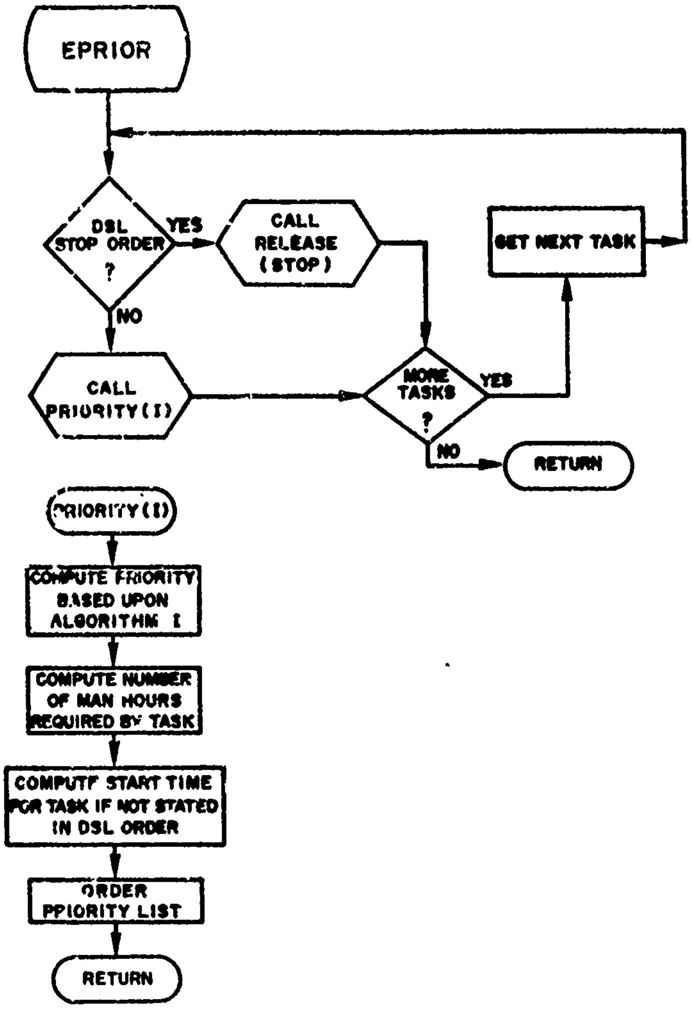

Figure 8-3. Engineer Priority Routine (EPRIOR)

(d) Calculates task execution time, including delays, and calculates the resultant task completion time.

(e) Provides to other routines information on the current relative priorities of tasks.

(f) Provides to the release routine information on task terminations.

(2) Relation to Other Major Components. See Figure 8-3.

(a) Inputs Received. From ENGR: Unordered task and priority list.

(b) Outputs Produced:

1. For EFEASI: Current ordered task priority list.

2. For EUPDAT: Current task priority information.

3. For ERELEA: Indication of reason for task termination; i.e., DSL STOP order or violation of FEBA constraint.

(3) Priority Determination. The allocation and scheduling of resources for engineer START tasks are based upon model comparison of 3-digit task priority indicators as shown in Figure 8-4. STOP tasks automatically receive top priority as they release engineer resources for START tasks. Each of the three indicator digits is considered individually.

(a) Structure and Function Indicator (A): This indicator is preset and is model-controlled during the game; its purpose is to provide the gross priority basis for all engineer START tasks. The value of this indicator is determined primarily by the urgency of the task. If the task is classified MANDATORY, this indicator is given a value of 1; if the task is classified DESIRED, this indicator is given a value ranging from 2 to 5 as shown in Figure 8-4, depending on three secondary conditions as follows:

1. The posture of the military force; i.e., offense or defense.

2. The type of structure involved; i.e., barrier or facility.

3. The nature of the task function involved; i.e., BUILD, BREACH, or REMOVE.

(b) Time Preference Indicator (B). This indicator is a variable and is based on the amount of time remaining until the scheduled clock time of the start of a task. Its purpose is to permit a shifting upward of the priority of a task as the need for the task becomes more imminent.

Item	Priority Indicator		
	A	B*	C*
	Structure and Function	Time Preference	Task Preference
SCALE OF PRIORITIES	1** 2 3 4 5	1 2 3 4	1 2 3 4
OFFENSE			
Facility			
Build	3		
Breach	4		
Remove	4		
Barrier			
Build	5		
Breach	2		
Remove	2		
DEFENSE			
Facility			
Build	5		
Breach	2		
Remove	2		
Barrier			
Build	3		
Breach	4		
Remove	4		

* Gamer specified each game period.
** Reserved for MANDATORY tasks.

Figure 8-4. Engineer Task Priority Indicators for START Tasks

(c) Task Preference Indicator (C). This indicator is designated by the gamer. Its purpose is to function as tie-breaker and establish task priority when the A and B priority indicators are identical; e.g., when two or more barriers are to be constructed at or near the same time. The gamer decides which task should have priority for resources.

(d) Priority Algorithm. The priority routine uses the following algorithm to compute an overall task priority for ordering the task priority listing:

$$PRTY = 16 * (FCNPRTY - 1) + 4 * (TIMPRTY - 1) + DSLPRTY \quad (8\text{-}1)$$

where:

PRTY indicates total or overall priority

FCNPRTY indicates the value of the structure and function indicator from Column A, Figure 8-4

TIMPRTY indicates the value of the time preference indicator from Column B, Figure 8-4

DSLPRTY indicates the value of the task preference indicator from Column C, Figure 8-4

This algorithm was designed to provide a basis for ordering of tasks in consonance with the general priority scheme.

(e) Man-hour Requirement Algorithm. The priority routine uses the following algorithms to compute man-hour requirements for a task:

1. If the task type is a minefield:

$$MHR = TSKSIZ * TSKRAT \quad (8\text{-}2)$$

where:

MHR = total man-hours required

TSKSIZ = Task size = length of minefield computed by using the distance formula between the two endpoints of the minefield segment

TSKRAT = task rate taken from Engineer Task File

2. If the task type is other than a minefield:

$$MHR = TSKSIZ * TSKRAT * PLATMEN * PLATNBR \qquad (8\text{-}3)$$

where:

TSKRAT = defined above

PLATMEN = standard number of men in a platoon (taken in the model as 120 for troop type 5, and 30 for all other troop types)

PLATNBR = standard number of platoons required for this task size, taken from Engineer Task File.

(f) Task Starting Time. The priority routine uses the following algorithms to establish task starting time:

1. If the task is generated by a DSL order which inclues the modifier START BY DDTTTT:

$$TSTART = DDTTTT \qquad (8\text{-}4)$$

where:

TSTART = task starting time

DDTTTT = date-time group indicating start time

2. If the task is generated by a DSL order which includes the modifier COMPLETE BY DDTTTT:

$$TBASIC = (60 * MHR) \div (PLATMEN * PLATNBR) \qquad (8\text{-}5)$$

if task type is a minefield, otherwise:

$$TBASIC = 60 * TSKSIZ * TSKRAT \qquad (8\text{-}6)$$

where:

TBASIC = basic time required for accomplishing task under condtions applicable to standard rates

$$TDELTA = TBASIC \div (RATMODTER * RATMODNIT) \quad (8\text{-}7)$$

where:

TDELTA = time required for accomplishing task under actual conditions with degraded rates

TBASIC = defined above

RATMODTER = terrain rate modifier from Engineer Task File

RATMODNIT = night rate modifier from Engineer Task File; equals 1.0 if night conditions are not involved.

$$TSTART = TCOMPL - TDELTA - TBUFFER \quad (8\text{-}8)$$

where:

TSTART = defined above

TCOMPL = DDTTTT = date-time group specifying completion time

TDELTA = defined above

TBUFFER = arbitrary buffer time allocated to cover contingency delays; equals 45 minutes if task is mandatory, otherwise equals 30 minutes.

3. If the task is generated by the Movement Model:

TSTART = earliest time task is found to be feasible.

d. Engineer Feasibility Routine (EFEASI) (Figure 8-5):

(1) Purpose. The feasibility routine functions as the second stage of the task filter and commits resources to feasible tasks in accordance with the requirements of the task. It performs the following specific functions:

(a) Determines the current feasibility of performing an engineer task based on the current status of task priority.

(b) Commits available resources to specific feasible tasks in order of priority when the task commitment is triggered.

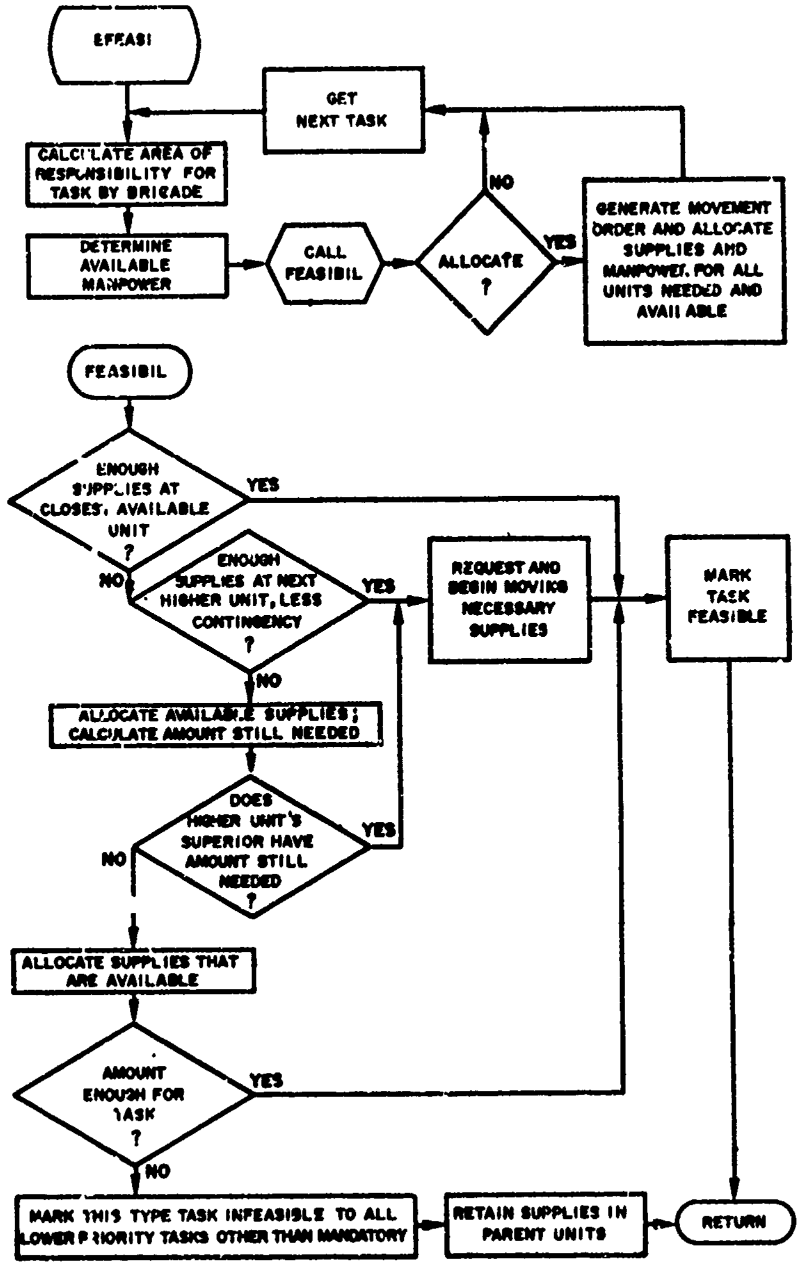

Figure 8-5. Engineer Feasibility Routine (EFEASI)

(c) Generates movement orders for troop units committed to tasks.

(2) Relation to Other Major Components. See Figure 8-5.

(a) Inputs Received. From EPRIOR: Current ordered task priority list.

(b) Outputs Produced:

1. For Unit Status File: Information on depletion of resources.

2. For ENGR: Engineer operating instruction.

3. For Movement Model: Movement orders for troop units committed to tasks.

(3) Feasibility Determination. EFEASI takes each task from the priority list by priorities from highest to lowest and, based upon task information in the Barrier-Facility File, computes the resources required for each particular task. It then compares resources required with resources available; when the latter are adequate, feasibility is established.

(a) EFEASI determines the troop requirement by examining the troop type number (from Barrier-Facility File) and the standard number required (from Engineer Task File), and using the following algorithm:

$$TRREQ = (TRUNITA + TRUNITB) * STDNR \qquad (8-9)$$

where:

TRREQ = troops required for task

TRUNITA = troop unit A = one bridge platoon if troop type number is 5, otherwise this is a null unit

TRUNITB = troop unit B = one combat engineer company if troop type number is 5, otherwise one combat engineer platoon

STDNR = standard number of units required for this task type.

(b) EFEASI determines the equipment and supply requirements by examining the task size and the current physical status of the barrier or facility and using the following algorithms:

$$EQPMULT = TSKSINR \div PROPFAC \qquad (8-10)$$

where:

EQPMULT = equipment or supply multiplier, a multiplying factor relating quantity of type equipment or supply required for this size task to the quantity required for a standard size task (this is determined for each item code involved)

TSKSINR = task size number determined by comparing task size value with task sizes found on scale of task sizes in Engineer Task File

PROPFAC = proportionality factor, a weighting factor used for adjusting equipment and supplies to fit variable task sizes; taken from Engineer Task File.

EQPREQ = EQPSTD * EQPMULT * CONFAC * RESRAT * FACFRAC (8-11)

where:

EQPREQ = total quantity of a line item equipment or supply required for this task

EQPSTD = standard quantity of this line item equipment or supply required for basic size task

EQPMULT = defined above

CONFAC = contingency factor to provide a cushion for losses due to enemy action; taken as 1.05 in the model

RESRAT = task restart ratio = 1-(MHRCMPLTD/MHRREQ)

MHRCMPLTD = total man-hours completed on task

MHRREQ = total man-hours required for task

FACFRAC = fraction of total facility or barrier comprising task; following values are used:

Task Function	Facility Does Not Exist	Facility Exists Intact	Facility Exists Breached
BUILD	1.00	0.00	0.33
BREACH	0.00	1.00	0.00
REMOVE	0.00	1.00	0.67

(4) Resource Allocation:

(a) EFEASI selects and disperses the necessary resources for the task, including troops, equipment and supplies. It locates the nearest suitable troop units and generates the movement orders. The Movement Model moves the units to the task site.

(b) If a task has been found to be infeasible because resources are inadequate to meet total requirements, but the resources are adequate to meet minimum requirements for starting the task, EFEASI allocates available resources; this task then has first priority over similar tasks for new resources when they become available.

(c) If a task has been found to be infeasible because resources are inadequate to meet minimum requirements for starting the task, EFEASI sets an insufficiency flag which prohibits allocation of resources to any other task of this type, except a task specified as MANDATORY, until the requirements of this flagged task have been met.

e. Engineer Update Routine (EUPDAT) (Figure 8-6):

(1) Purpose. This routine evaluates every engineer activity in progress and updates the status. It performs the following specific functions:

(a) Sets task-in-process flag when resources on hand at a task site are adequate for starting work.

(b) Provides resource update information for task units.

(c) Updates manpower on a task site and mobilizes more manpower if current manpower is inadequate for the task.

(d) Calcualtes task performance rates and the related portion of the task completed each clock period.

(e) Enters updated task information into the Barrier-Facility File.

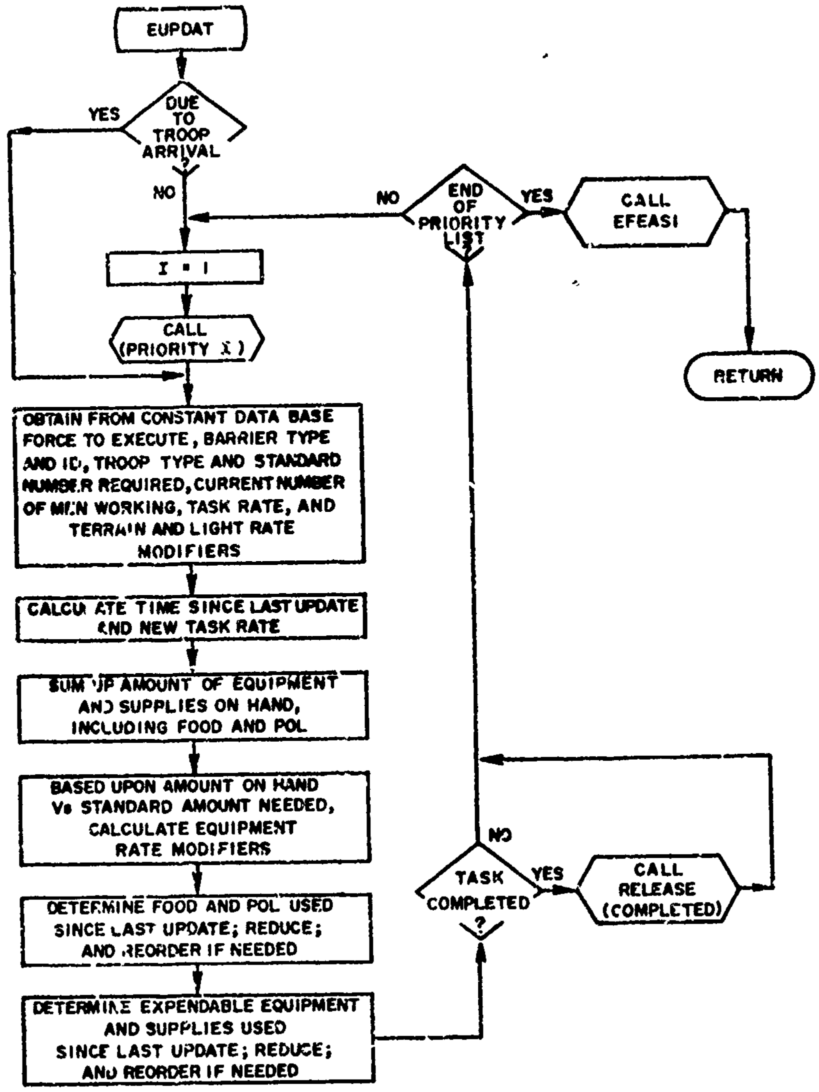

Figure 8-6. Engineer Update Routine (EUPDAT)

(f) Advises the release routine of each task completion and triggers the release of engineer forces upon completion of each task.

(2) Relation to Other Major Components: See Figure 8-6.

(a) Inputs Received. From EFEASI (indirectly through the Movement Model): Resources allocated to a task.

(b) Outputs Produced:

1. For Unit Status File, Unit Equipment File, and Barrier-Facility File: Update information on task status.

2. For ERELEA: Task completion information and triggering for demobilization of task units.

(3) Update Procedures:

(a) EUPDAT reevaluates the priorities of all tasks the model has requested except those with priority 5000, examines resources versus time remaining to complete the task, and reallocates resources to tasks in progress until they have their full quotas of resources.

(b) EUPDAT decrements in most cases the proper item codes by the amount expended since the last previous update, and outputs updated information to the Barrier-Facility File.

(4) Update Algorithms. The update routine uses the following algorithms to compute man-hours expended for updating of the Barrier-Facility File:

$$TSKRATAD = TSKRAT \div (RATMODTER * RATMODUNIT * RATMODEQP) \quad (8\text{-}12)$$

where:

TSKRATAD = adjusted task rate

TSKRAT = task rate taken from Engineer Task File

RATMODTER = terrain rate modifier from Engineer Task File

RATMODNIT = night rate modifier from Engineer Task File; equals 1.0 if night conditions are not involved

RATMODEQP = product of equipment rate modifiers for equipments involved in task; individual modifiers are taken from Engineer Task File.

$$TPROP = TELAP \div TSTDPD \tag{8-13}$$

where:

TPROP = time proportion; i.e., fraction of a standard time period that has passed since last update

TELAP = elapsed time since last update

TSTDPD = standard time period; 15 minutes is taken in Engineer Model.

$$MHREXP = \frac{TPROP * TSKSIZ * MENNBR}{TSKRATAD * PLATNBR * PLATMEN * STDPDPHR} \tag{8-14}$$

where:

MHREXP = total man-hours expended since last update

TSKSIZ = task size (as computed for minefields, or as taken from Barrier-Facility File for other type tasks)

MENNBR = actual number of men in units assigned to task site

TSKRATAD = defined above

PLATNBR = standard number of platoons required for this task size, taken from Engineer Task File

PLATMEN = standard number of men in a platoon (taken in the model as 120 for troop type 5, and 30 for all other troop types)

STDPHPHR = number of standard time periods per hour, taken as 4 in the model.

f. Engineer Release Routine (ERELEA) (Figure 8-7):

(1) Purpose. This routine demobilizes mission units and resources whenever there is reason for stopping a task. it performs the following specific functions:

(a) Teminates tasks when tasks are completed, when a DSL STOP order is received, or when a specified FEBA condition exists.

(b) Generates movement orders for demobilization of task troop units when a task is completed or terminated.

(c) Notifies Movement Model of completion or termination of tasks requested by that model.

(d) Updates facility status in Barrier-Facility File on completion or termination of task.

(e) Provides period status for end-of-period Barrier Report.

(f) Removes completed tasks from the task priority list.

(2) Relation to Other Major Components. See Figure 8-7.

(a) Inputs Received:

1. From EPRIOR. Indication of reason for task termination; i.e., DSL STOP order or violation of FEBA constraint.

2. From EUPDAT: Task completion information and triggering for demobilization of task unit

(b) Outputs Produced:

1. For Barrier-Facility File: Facility status update, both physical and intelligence.

2. For EPRIOR: Removal of completed task from task priority list.

3. For Movement Model:

a. Movement order for task troop units requiring demobilization.

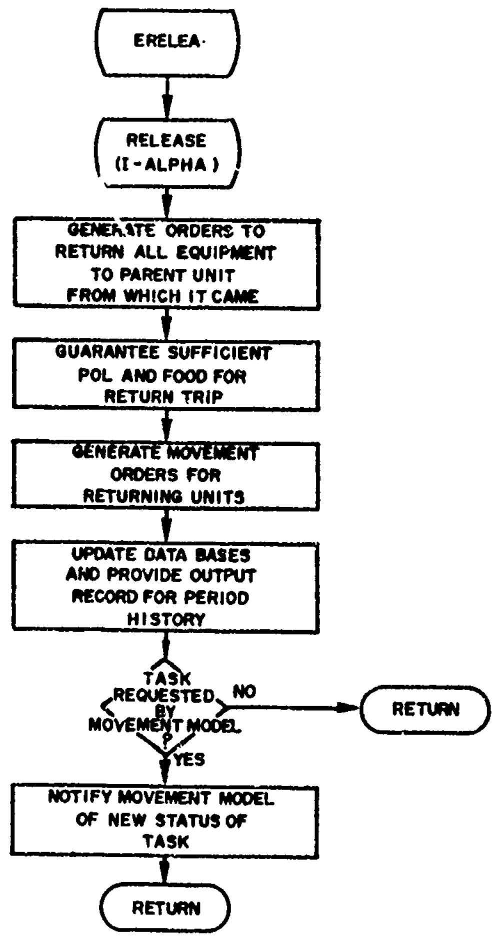

Figure 8-7. Engineer Release Routine (ERELEA)

b. Task completion notice for tasks requested by the Movement Model.

4. For end-of-period Barrier-Report: Period status.

(3) Release Procedures:

(a) Two conditions are cause for release action: a task is completed, or a DSL order is a STOP order. In either of these cases, immediate priority is given to ERELEA along with the reason for termination.

(b) ERELEA generates movement orders for released units; Movement Model returns these units to their parent units.

(c) ERELEA incorporates the task status information into the Barrier-Facility File and, if the task was one requested by the Movement Model, advises that model of the task status.

g. Engineer Nuclear Routine (ENUCLE) (Figure 8-8):

(1) Purpose. This routine handles the Engineer Model aspects of radiological barriers created by nuclear events and nuclear effects damage to existing barriers/facilities. It performs the following specific functions:

(a) Establishes, updates, or removes radiological barriers as appropriate when furnished nuclear event information or update information.

(b) Notifies Nuclear Assessment Model of existing barriers lying partially or wholly within the radius of effects of nuclear events.

(c) Records reported nuclear effects damage to existing barriers/facilities and outputs this information for report purposes.

(2) Relation to Other Major Components. See Figure 8-8.

(a) Inputs Received:

1. From ENGR: Indication of type action required.

2. From Nuclear Assessment Model:

a. Notification of nuclear events and their descriptions.

b. Update information for radiological barriers.

c. Assessed nuclear effects damages to existing barriers/facilities.

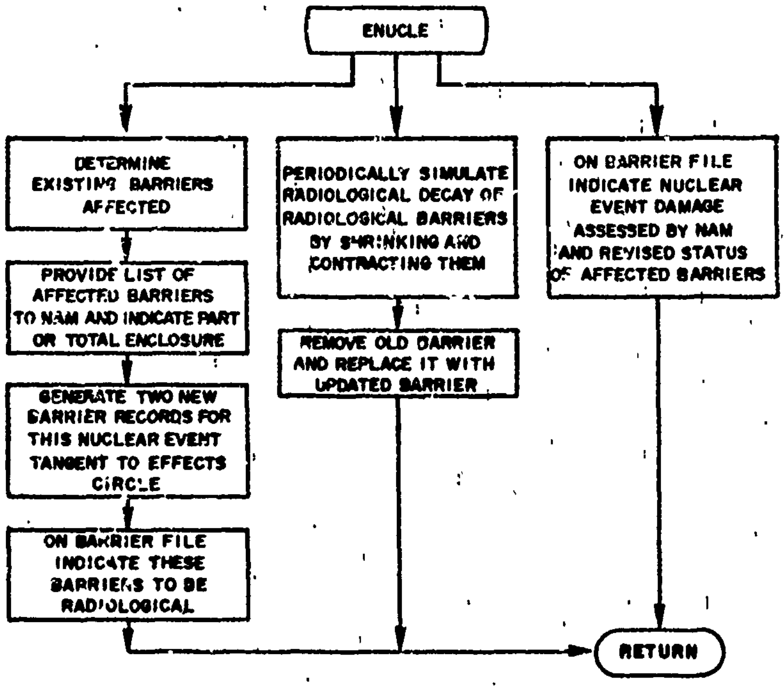

Figure 8-8. Engineer Nuclear Routine (ENUCLE)

(b) Outputs Produced:

1. For Nuclear Assessment Model: List of barriers/facilities lying partially or wholly within the radius of effects of a nuclear event.

2. For end-of-period Barrier Report: Status of barriers/facilities damaged by nuclear effects.

(3) Procedures. Details of the procedures involved are covered in the discussion of the interface between the Engineer Model and the Nuclear Assessment Model, subparagraph 2c(2) above.

CHAPTER 9

COMBAT SERVICE SUPPORT MODEL

1. MILITARY ACTIONS REPRESENTED:

a. General. Personnel, major end items, and combat essential materiel must be replaced within a military unit when required. If the unit does not have a ready source of personnel and materiel, the capability of the unit to accomplish its mission is severely limited. The DIVWAG Combat Service Support (CSS) Model simulates personnel replacement, resupply of critical consumables and expendables, and resupply of major end items. The model does not simulate resupply of repair parts. The resupply or replacement process is treated in three essential areas; ordering, distributing, and receiving supplies. These aspects of resupply are simulated differently for critical consumables and expendables (Classes III and V) and for personnel, Class I, and major end items.

b. Resupply of Critical Consumables and Expendables:

(1) Ordering. The process of ordering supplies requires the determination of the quantity to order, when to order, and the priority of the order.

(a) The quantity to order is based on projected usage. Within the model, a mean use rate is determined by combining the current usage rate with past usage rates to develop a long term projected usage rate. The amount of variance that this mean rate will have is estimated in order to place a confidence limit on the forecasted rate. Weighting factors are used to retard the transition from past usage history to present usage rate, thus smoothing out random fluctuations in the rate. Included in the calculation of the projected rate of usage is a safety level to provide protection against stock outages. A safety level is that quantity of materiel (in addition to operating stocks) required to permit continued operations in the event of variations above the projected usage rate or unanticipated delays in resupply. The projected usage rate is the basis for calculating the quantity to order.

(b) The time at which supplies are ordered depends on projected usage and a reorder cycle time. Within the model, an order is initiated to allow supplies to reach the unit as required to keep the unit near its authorized level of supplies. This determination is based on the projected usage rate, including safety level, a nominal order and shipping time, and any amount already on order.

(c) The priority of an order is dictated by the mission of the using unit and the criticality of the supplies to that mission. Within the model, highest priority is assigned to resupply of the front line maneuver units. Second highest priority is assigned to all other maneuver units and

all artillery units. The lowest priority is assigned to other units not included in the first two priorities. Among the orders for supplies generated by each group of units, a second priority is applied. This priority is based on the criticality of supplies to the unit.

(2) Distribution of Supplies. In treating supply distribution, the distribution method or policy, routing, and treatment of materiel upon receipt must be considered.

(a) Method of Distribution. The Army supply system utilizes two methods of distribution; unit distribution and supply point distribution. Unit distribution refers to the delivery of supplies from the supplying activity to the consuming unit, and supply point distribution requires the consuming unit to pick up supplies from the supplying activity using its own personnel and vehicles. Both methods of distribution are treated in the Combat Service Support Model. If one method of distribution is impossible because of lack of sufficient transportation means, the model automatically attempts to effect the supply action using the other method of distribution.

1. In unit distribution all supplies requested are transported to the requesting unit on vehicles provided by the supplying unit. If there are not enough available supplies, the unfilled portion of the order remains due until they become available. The order and shipping times for unit distribution include the times required to place and fill the order, load the vehicles, transport the supplies, and unload them and make the supplies available to the using unit.

2. In supply point distribution the unit needing supplies must provide its vehicles and send them to the supply point. Order and shipping times in supply point distribution include the times required to move the vehicles to the supply point, pick up supplies, and return to the unit.

3. The model will attempt to airlift supplies if sufficient ground transportation is not available and the supplies are critical to the receiving unit.

4. If a unit is involved in an airmobile operation, it is not resupplied until the airlift has been completed. If the unit is airlifted into hostile territory, resupply is only effected through airlift operations; otherwise, resupply is handled in the same manner as described above.

(b) Routing. Materiel may pass through a number of intermediate holding or handling points as it progresses from an original source of supply to the ultimate user. Within the model intermediate and initial supply points are treated. Intermediate supply points function similarly to the ultimate using unit insofar as the process of obtaining supplies is concerned; an intermediate supply point has a point of supply identified from which it

may obtain the required items by unit or supply point distribution, based on a projected use rate. For such intermediate supply points, usage rate is based not only on the supply point's consumption but, more importantly, on the amounts of materiel supplied to other units. An intermediate supply point may temporarily run out of supplies if the demand exceeds its on-hand stocks and resupply capability. Initial supply points are treated within the model as being unlimited sources of supply. The routing of supplies to a using unit through intermediate supply points or directly from an initial supply point is established as part of the force's task organization through gamer input.

(c) Treatment Upon Receipt. Upon receipt of supplies, the using unit will generally hold the supplies in bulk until such time as it is necessary or convenient to distribute them to the ultimate user. For example, bulk ammunition may be held in the combat trains of a maneuver unit for some period of time until its distribution among the weapons systems that will fire the ammunition can be effected. Within the model, every unit which will receive supplies is treated as having a holding point for bulk supplies, nominally the unit combat trains. Supplies are delivered to the trains and transferred from trains to the unit's using entities on a periodic basis. As currently programmed this process is accomplished once every two hours.

(d) Materiel Flow. Figure 9-1 illustrates the basic flow of materiel from an initial supplier, to the nominal trains of an intermediate supplier, to the intermediate supplier's using (in this case shipping) entities in the using unit. Zero, one, or more than one intermediate suppliers may be involved. The figure also illustrates the basic flow of personnel, major end items, and Class I consumables in which all nominal trains are bypassed.

c. Resupply of Personnel, Major End Items, and Class I:

(1) Resupply of Major End Items:

(a) To accomplish the resupply of major end items, the pregame data load specifies by item code which items active in the game are to be treated as major end items, the amount of each item available for replacement during each 24-hour increment, and if separate transport is required, the equipment item to transport each item to be replaced.

(b) To establish the quantity of items available for resupply, a multiple class supply point which controls receipt and issue of major items is established within the model. This point contains all items available for resupply where the amount available on a given day is the accumulation of amounts specified by input for that and all previous days, less the amount that has actually been sent to using units. The basic assumption is that limited stocks are available in division maintenance floats and rear service areas. Initial stocks and daily replenishment quantities can be specified in the constant data input.

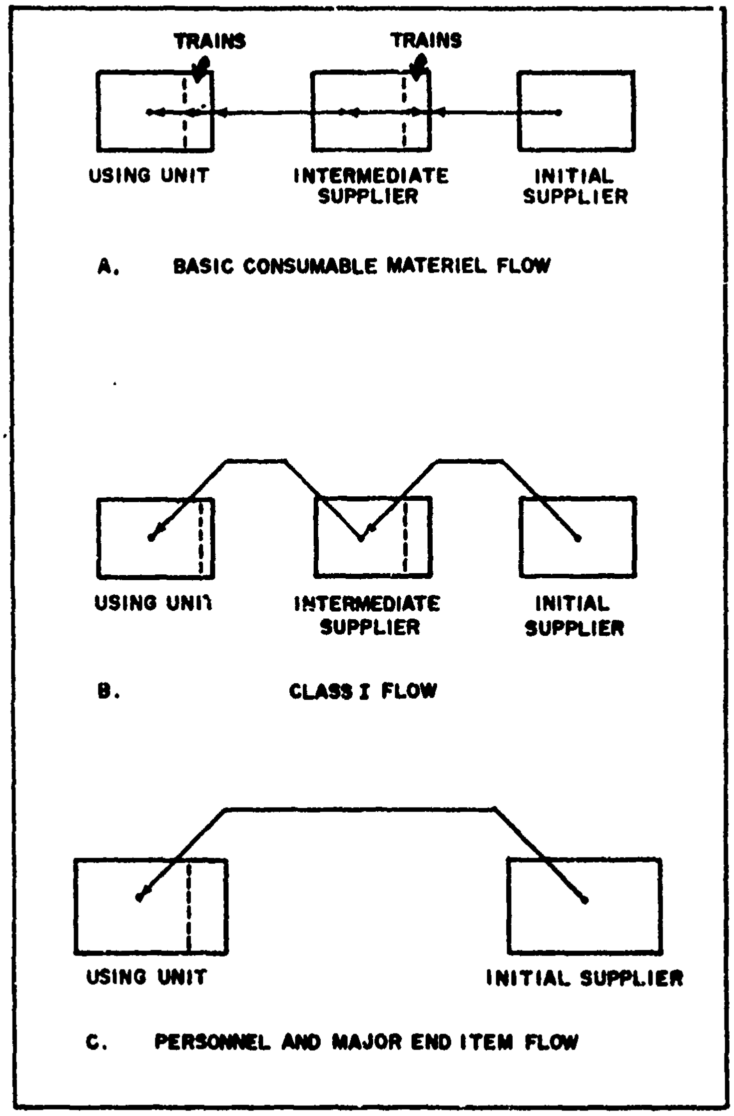

Figure 9-1. Flow of Resupply Actions in Combat Service Support Model

(c) To determine units receiving major items, a type of daily loss report which serves as a requisition is developed for each unit active in the game. Units are resupplied within three groups with first priority to front line maneuver units, second priority to other maneuver units and artillery units, and third priority to all other units. If insufficient items are available to meet all requirements within a priority group, available items are prorated according to needs. For example, if unit A requires 10 items and unit B requires 20 items and only 15 are available, unit A will receive 5 items and unit B will receive 10 items. An item will move from the supply point to the receiving unit at the road movement rate of the item, if self-transportable, or of the transporter, if not self-transportable.

(2) Resupply of Class I:

(a) Class I supplies are items consumed at a uniform and predictable rate, irrespective of combat or terrain conditions, and require no adaptation to individual requirements (FM 17-1). Within the model Class I supplies consist of rations. In the division, a formal requisition for Class I supplies is not required. The division supply and transport battalion requests rations for the division, based on estimated strength figures provided by the adjutant general, 72 hours before the time rations are to be delivered. Upon receipt, rations are broken down into battalion and separate unit lots based on personnel daily summaries submitted by each unit. In rapidly changing situations, it may be necessary for units to submit daily informal requisitions for the number of rations required. These requisitions compensate for cross attachments and casualties.

(b) In the model Class I is resupplied daily. It is assumed that units submit daily informal requests for number of rations required. Requisitions compensate for cross attachments and casualties. The resupply level of a unit is based on the number of personnel attached to the unit at the time resupply is to occur. This time is fixed within the model at 0400 hours. Once the number of personnel in a unit is determined, the resupply quantity is calculated on a pounds per man per day basis. The Class I consumables are delivered directly to the using units.

(c) The main purpose for modeling Class I resupply is to constrain the transportation available to resupply other commodities, primarily ammunition and fuel. It is assumed that battalions and separate units use organic transportation to pick up rations at the division Class I distribution point in the brigade trains area. If all food ordered cannot be delivered at the first attempt, the unfilled orders remain due out. At each succeeding hourly update attempts are again made to fill the remaining Class I orders. No new Class I orders are generated for 24 hours, but the unfilled orders are retained until filled. Unlike Class I, all other consumables that cannot be delivered as scheduled have new backorders created at each update.

(3) Personnel Replacement:

(a) All replacements received by the division are processed by the replacement detachment, which is under the control and supervision of the adjutant general. The normal capacity of the detachment is 300 replacements at one time and can be increased if additional control personnel and equipment are provided.

(b) Replacements are assigned to the division on the basis of daily replacement status reports submitted to higher headquarters by the division adjutant general. These reports are based upon TOE position vacancies as shown in unit morning reports. Replacements are provided from personnel arriving from the zone of interior, hospital returnees, personnel being rotated from other areas, and casualties being returned to duty from various sources. Replacements, even in combat, are obtained through formal requisitioning procedures. Replacement personnel are requisitioned to replace actual losses in TOE positions only. Replacements cannot be requisitioned for a unit in advance of its needs.

(c) Personnel requisitions are modeled as follows:

1. Company commanders do not requisition replacements; however, they do submit morning reports or feeder morning reports, showing company personnel losses, through battalion to division. The company commanders receive, orient, and assign replacements upon arrival at the company.

2. The battalion S1 does not requisition replacements. He monitors the morning reports or feeder morning reports of the subordinate units to ascertain that the units have included known losses on the reports.

3. Upon notification that replacements are available, the battalion S1 coordinates directly with the S3 and appropriate special Staff Officers to determine battalion priorities and then informs the division AG of the priority of assignment to the companies. The AG publishes division special orders assigning the individual to his company directly from the division replacement company.

(d) Within the model personnel replacement occurs once each day at a predetermined hour. Time of replacement is fixed in the model at 1000. hours. The number of personnel replaced is based on two factors which are type of unit and current strength of a unit. Data are input to specify number of replacement personnel available during each 24 hours of game play. If sufficient personnel are not available to bring all units up to their authorized levels, the priority of replacement is front line maneuver units, artillery and other maneuver units, and all other units. Within priority groups, available replacements are evenly prorated according to a unit's losses. Personnel are resupplied directly to the using unit. Within the model, no attempt is made to replace personnel by grade or military occupation specialty.

(e) Replacement of personnel follows the logic developed for resupply of principal items. Personnel are only requested once per day based on combat losses.

2. MODEL DESIGN:

a. Model Logic. The basic logical flow of the Combat Service Support Model is shown in Figure 9-2. The sequence of processing groups of units shown in the figure imposes a priority on the units to be serviced. In resupplying critical consumables and expendables, transportation resources available to both the supplying and receiving units are used in allocating transport. Thus, by the time the second and third groups of units are processed, transportation organic to the supply point may have already been allocated to service higher priority units. In the case of personnel and major end items only a limited number of replacements is available. Resources are allocated with first priority to front line maneuver units, second priority to other maneuver units and artillery units, and third priority to all remaining units. The dynamic data files and the significant model steps used in the model logic are identified below and discussed in detail in Paragraph 3.

b. Dynamic Data Files. The Combat Service Support Model uses four dynamic data files: the Unit Status File, the Supply Action File, the Supply Status File, and the Backorder File.

(1) The Unit Status File is described in Chapter 2. This file contains information on the current status of each unit involved in the game, updated as a result of any simulated activity involving the unit. It contains the quantities of equipment currently on hand in each unit and points to the unit's records on the Supply Status File.

(2) The Supply Status File contains information pertaining to the current supply status of a unit. For every resolution unit in the game, one record is maintained on this file for each equipment item that may be supplied to the unit. (See Chapter 2 for a discussion of resolution units.)

(3) The Supply Action File contains a record for every supply action currently in process. A supply action is the movement of an equipment item order quantity with its associated transportation resources from the supply point to the unit or the movement of the transportation resources alone from the unit to the supply point. These records are updated as the order quantity and transporting vehicles progress between supply points and receiving units.

(4) The Backorder File maintains a record of each supply requirement for which a supply action must be initiated.

c. Model Steps. As shown in Figure 9-2, the major Combat Service Support Model steps are: (1) updating Supply Action File entries, (2) creating resupply orders and assigning transportation to fill the resupply orders for

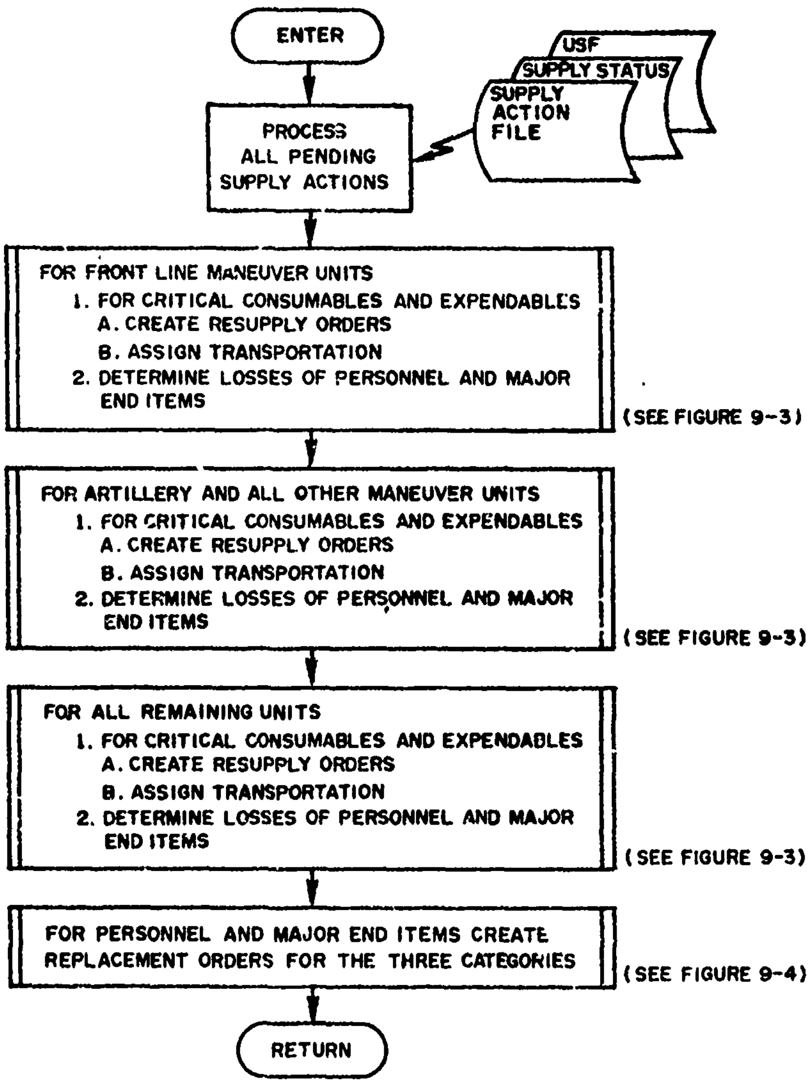

Figure 9-2. Combat Service Support Model

critical consumables and expendables, (3) determining losses of personnel and major end items, and (4) creating replacement orders for personnel and major end items. The model is generally entered on a periodic basis (currently once every two hours in the DIVWAG system), and all pending supply actions are processed. Next, for each force Steps 2 and 3 are accomplished sequentially for each of three groups of units; front line maneuver units, other maneuver units and all artillery units, and all other units. This sequence of unit groups imposes a first priority level on the assignment of transportation. Finally, after Steps 2 and 3 are completed for all units, personnel and major end item replacement orders are created sequentially for the three unit groups.

3. SUBMODEL SPECIFICATIONS:

a. Processing of Critical Consumables and Expendables:

(1) General:

(a) Figure 9-3 shows the processing logic which occurs within a group of units to resupply critical consumables and expendables. Since major end items and personnel are resupplied only once a day, a check has been incorporated to determine on which processing cycle their resupply is to be initiated. At the appropriate time, losses of major end items and personnel are accumulated for each unit. The actual requisitioning of major end items and personnel does not occur on this first pass through the units (see Paragraph 3b).

(b) Since Class I (food) is to be ordered only once a day, a check has been entered to determine when that time occurs. Only at the specified time is Class I ordered. The quantity ordered is based on the personnel strengths of the units at the time the order is initiated.

(c) The flow of logic illustrated in Figure 9-3 can be broken into three logical processes: the determination of supply requirements, the allocation of available transportation means to meet supply requirements, and the supply actions involved in actually fulfilling supply requirements utilizing the allocated transportation. Details of these processes are contained in the following subparagraphs.

(2) Determination of Supply Requirements. The method used within the Combat Service Support Model to determine supply requirements draws upon basic logistic management techniques found in FM 38-22. A simplified variation of the Optimal Replenishment Inventory Model, modified for compatibility with the DIVWAG system, is used.

(a) Inventory Model. Figure 9-4 illustrates the operation of the inventory model used to establish the supply requirement for a given item. The model is based on a periodic review (once every two hours as now programmed) of the status of every item to be resupplied within every resolution unit in the

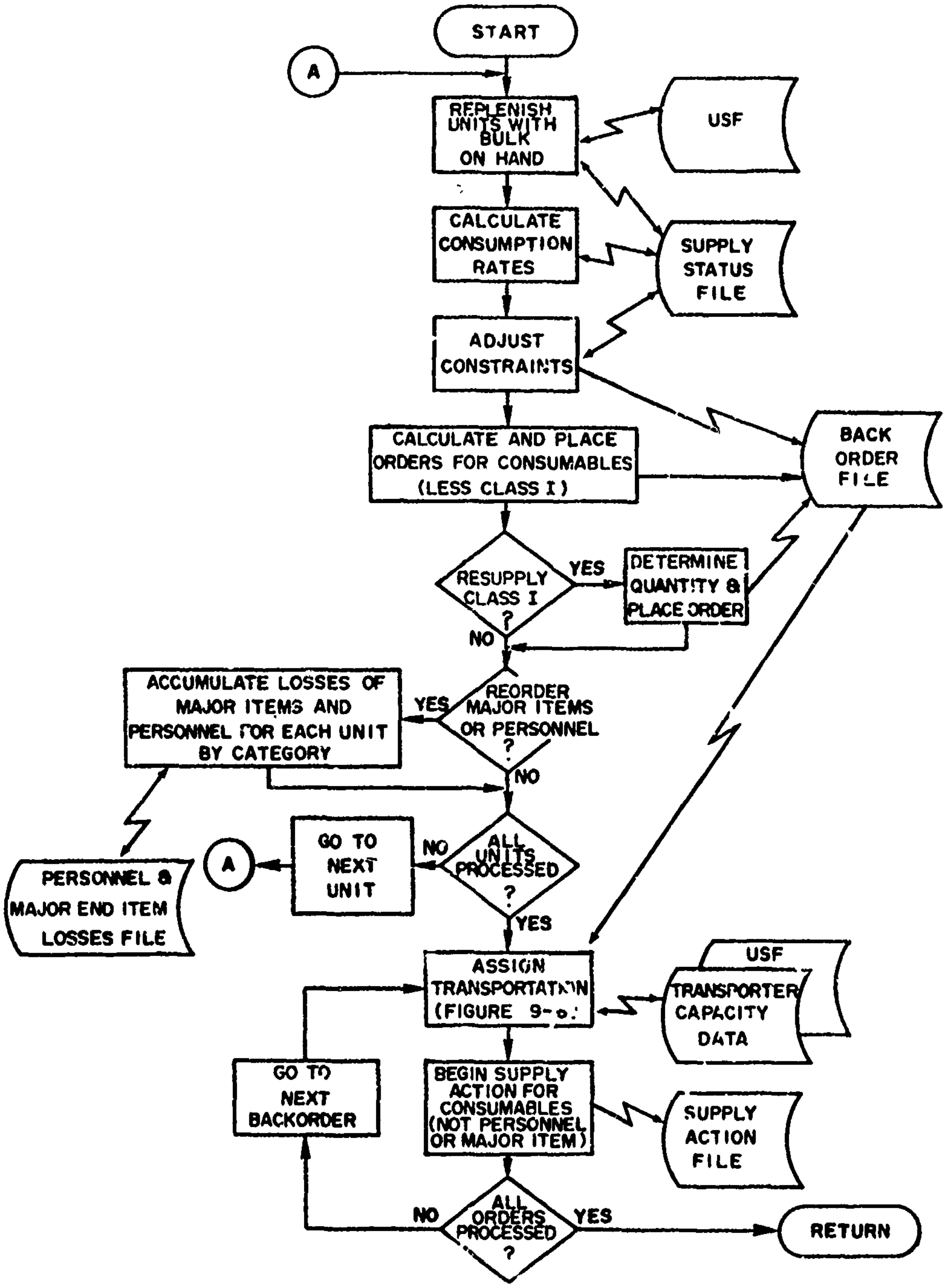

Figure 9-3. Processing of Critical Consumables and Expendables

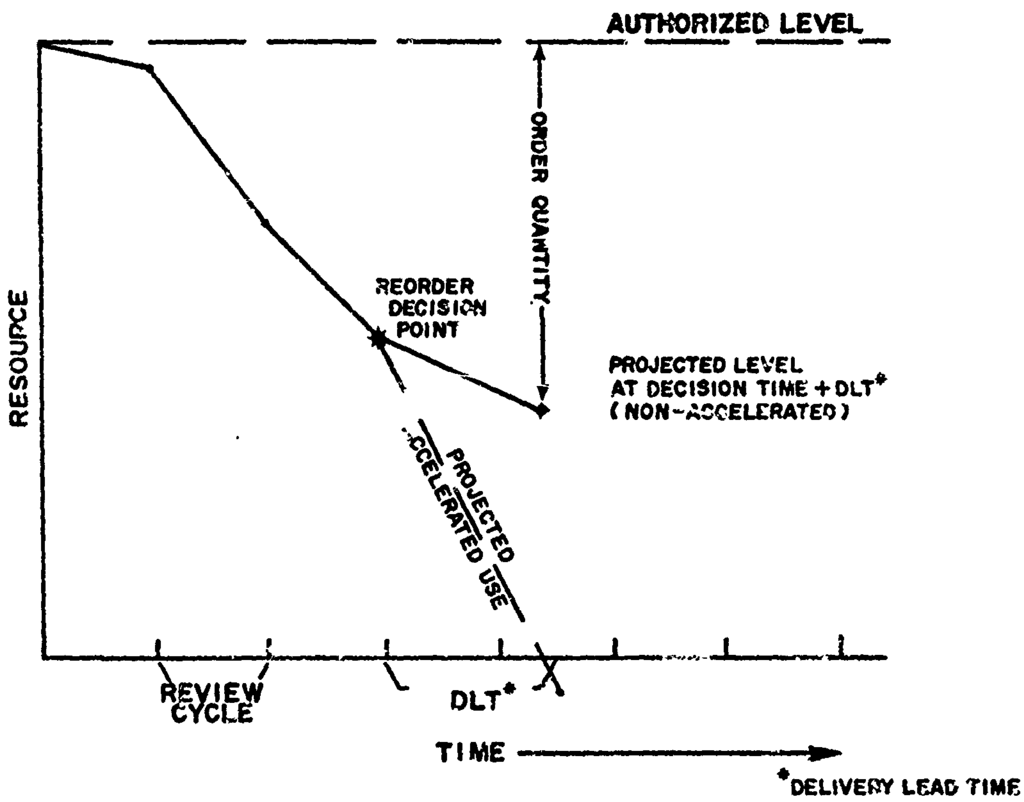

Figure 9-4. Basic Inventory Model Schematic

war game. At each review period, the projected usage rate, $\bar{r}$, and the mean average deviation, s, of that usage rate are calculated based on the exponential averaging technique of FM 38-22. These values are combined to develop an accelerated usage rate, r_q, which should not be exceeded in nine cases out of ten, under the assumption that the usage rate of the items involved follows a normal distribution. In the figure, $\bar{r}$, for a given review cycle is the negative slope of the current supply level line, and r_q is the negative slope of the projected supply level line. Next, the delivery lead time (DLT), or the amount of time in which this unit could expect delivery of supplies, is found; and the projected supply level at current time plus DLT is calculated using the accelerated usage rate and compensating for any supplies already on order. If this projected level is negative, a supply order is placed. The amount ordered is the difference between authorized and projected levels (where this projected level uses the nonaccelerated projection rate), compensating again for items already ordered. During this process, stocks are transferred, within the unit, from a bulk loaded status to a readily usable status; and a constraint factor, reflecting the emergency of the order, is calculated for later use in assigning a priority to the order.

(b) Calculation of Usage Rates:

1. In calculating usage rates, the model uses the amount of the item currently in a readily usable status, e_r, currently on hand but bulk loaded, e_t, and the amounts authorized in these categories, a_r and a_t. The projected usage rate is calculated by Equation 9-1.

$$\bar{r}_i = A \cdot \bar{r}_{i-1} + B \cdot r \qquad (9\text{-}1)$$

where:

$\bar{r}_i$ = projected usage rate for this review period

$\bar{r}_{i-1}$ = projected usage rate for the previous period

A = .75 [1 - exp - (h/12)]

B = 1 - A

r = $[(a_r - e_r) + TR] / t_r$

h = number of hours into the game

t_r = review period (120 minutes)

TR = amount shifted from e_t to e_r during the review cycle in response to emergency requests.

This is a variation of the basic exponential smoothing equation, in which A and B are constants. As originally designed, the values of A and B were .75 and .25, respectively. These are arbitrarily chosen smoothing constants intended to give a fairly gradual transition from past to current history. They are subject to adjustment. The correction factor to A is used to dampen the effects of the start of game situation in which no prior usage rate is available. The value of r is used to represent the usage rate since the last review cycle. After r has been computed, the amount of items available for use, e_r, is brought up to its authorized level, a_r, or as close thereto as stocks in bulk, e_t, permit. The equations used are:

$$e_r' = e_r + \min\left[(a_r - e_r), e_t\right] \qquad (9\text{-}2a)$$

$$e_t' = e_t - \min\left[(a_r - e_r), e_t\right] \qquad (9\text{-}2b)$$

where the prime (') denotes the value after adjustment. These are the same equations used to transfer items from a bulk to a readily available status in an emergency call to the model. It should be noted that r is the true usage rate only if e_r was at its authorized level at the beginning of the review cycle. In other cases, it indicates a serious deficit which will tend to increase over time, thus inflating $\bar{r}$ and driving the model to a more immediate supply order action.

2. The mean average deviation of the projected usage rate is calculated using the same exponential smoothing weights:

$$s_i = As_{i-1} + B \cdot \left| r - \bar{r}_{i-1} \right| \qquad (9\text{-}3)$$

where:

s_i = mean average deviation of $\bar{r}_i$

s_{i-1} = mean average deviation of $\bar{r}_{i-1}$

and other variables are previously defined.

3. The accelerated usage rate, r_q, is calculated as:

$$r_q = \bar{r}_i + (1.3 \cdot 1.25 \cdot s_i) \qquad (9\text{-}4)$$

where the constant 1.3 is used to give the approximate ninetieth percentile of a normal distribution, and 1.25 is the conversion factor from the mean average deviation to the standard deviation as provided in FM 38-22.

(c) Projected Outage. The projected outage situation, using the accelerated usage rate, is determined by Equation 9-5:

$$Q = e_r + e_t + e_o - r_q \cdot d \tag{9-5}$$

where:

Q = outage indicator

e_o = amount of the item currently on order and in the process of being delivered

d = delivery lead time

e_r, e_t, r_q = previously defined.

The amount currently in the process of being shipped is determined by a review of all pending Supply Action File records for which the unit involved is the recipient. This file is described in more detail in Paragraph 3d. The delivery delay time, d, is determined by Equation 9-6:

$$d = h_d \, (t_{tran} + t_{OH}) \tag{9-6}$$

where:

d = delivery lead time

h_d = 1 if the unit receives unit distribution of the item

h_d = 2 if the unit receives the item by supply point distribution

t_{tran} = nominal transport time

t_{OH} = overhead time.

Nominal transport time for this item is determined considering the distance between the unit and its supplier and the preferred transport vehicle. The supplier is identified as part of the original game task organization input. The preferred transport vehicle for this item and this distribution method is part of the Combat Service Support Model data base, required as input prior to game initiation. The model obtains (within Movement Model constant data) the limiting road speeds of the preferred vehicle, under current weather and light conditions; averages the speeds, which are given for two terrain

conditions; and applies this average speed to the distance between supplier and supplied to develop a nominal transport time. Overhead time, also part of the game data base, is intended to represent normal lumped overhead for filling an order, loading and offloading vehicles, and any other actions, exclusive of travel time, associated with a request for this item. If the value of Q in Equation 9-5 is negative; i.e., projected usage within delivery lead time exceeds stocks on hand and on order, a new order is generated. If an outage is projected, the amount ordered is calculated by Equation 9-7:

$$a_o = a_r + a_t - [e_r + e_t + e_o - \bar{r}_i d] \qquad (9\text{-}7)$$

where a_o = amount of order, and the other variables are previously defined. The quantity in brackets in Equation 9-7 is identical to the calculation of Q in Equation 9-5, with the projected usage rate substituted for the accelerated rate. In both cases, this is the projected level of supply of the unit just prior to receipt of supplies if ordered at this time under the appropriate use rates. The difference between these levels is the variable safety level of the logistic model, a function of the mean average deviation of the projected usage level and the delivery lead time:

$$SL = d(r_q - \bar{r}_i) = d \cdot 1.625\, s_i \qquad (9\text{-}8)$$

SL = safety level.

(d) Constraint Factor. Once a supply order is generated, it must compete with other orders for available transportation means. To allow assignment of priorities among supply orders, a constraint factor is computed for each item at each review period:

$$c_i = c_{i-1} \cdot \exp(1 - \bar{r}_i/m) \qquad (9\text{-}9)$$

where:

c_i = constraint factor for current review cycle

c_{i-1} = constraint factor of last review cycle

$\bar{r}_i$ = current projected usage rate of Equation 9-1

m = minimum rate (Equation 9-10).

The constraint factor is allowed to operate on the scale $.001 \leq c \leq 1$ with a lower constraint indicating higher priority. In the calculation, c_i is set equal to 1 if Equation 9-9 exceeds one. To avoid zero a value of c_i less than .001 is set to .001. Zero would be continuously generated once achieved. The minimum rate, m, is the usage rate that would allow on hand quantities to equal zero when projected to the nominal delivery lead time:

$$m = (e_r + e_t + e_o)/d \qquad (9\text{-}10)$$

Inspection of Equation 9-9 shows that the constraint factor gets small (high priority) very rapidly as $\bar{r}_i$ exceeds m and, conversely, the constraint increases (lower priority) if $\bar{r}_i$ is less than m.

(3) Assignment of Transportation. Once the supply status of all units within a group of units has been reviewed and any necessary supply orders generated, transportation is assigned to meet the supply requirements. Each supply order generated by the group of units is processed based on the priority of the order; i.e., the order with the lowest constraint factor of Equation 9-9 is processed first, then the order with the next lowest constraint factor, and so on. Thus, within the group of units, no priority is assigned to an individual unit. Rather, priority is based on the urgency of the supply order as compared with all orders generated by the group of units. As currently designed, no attempt is made to allocate transportation from the total force resources. Rather, for each supply order, only transportation organic to the requesting unit and the designated point of supply is considered.

(a) Logical Flow. The logical flow of the transportation assignment algorithm is shown in Figure 9-5. For each unit type and each item to be resupplied, an SOP distribution method is defined in the data base (unit or supply point distribution). Each item also has an associated supply class. Three preferred vehicles are designated for each distribution method as well as for air transport. Upon entry to the algorithm, the SOP distribution method is first attempted. The preferred vehicles are taken in order and assigned to transport the quantity ordered. If sufficient numbers of the first choice vehicle are available in the requesting (supply point distribution) or supplying (unit distribution) unit, processing is completed. If insufficient vehicles are available, all available vehicles are assigned and the process is repeated for the remaining order quantity using the second choice vehicle. If the order is still unfilled, available third choice vehicles are assigned. Once all available vehicles under the preferred distribution method have been assigned, the same process may be repeated for the preferred vehicles available in the other unit, under the remaining distribution method, always working on the unfilled portion of the order. If the order remains unfilled under both ground distribution methods, a third cycle may be tried, attempting to use air transport. The decision to attempt the alternative ground transportation method and air transportation is based on the constraint factor, c_i (priority), of the item.

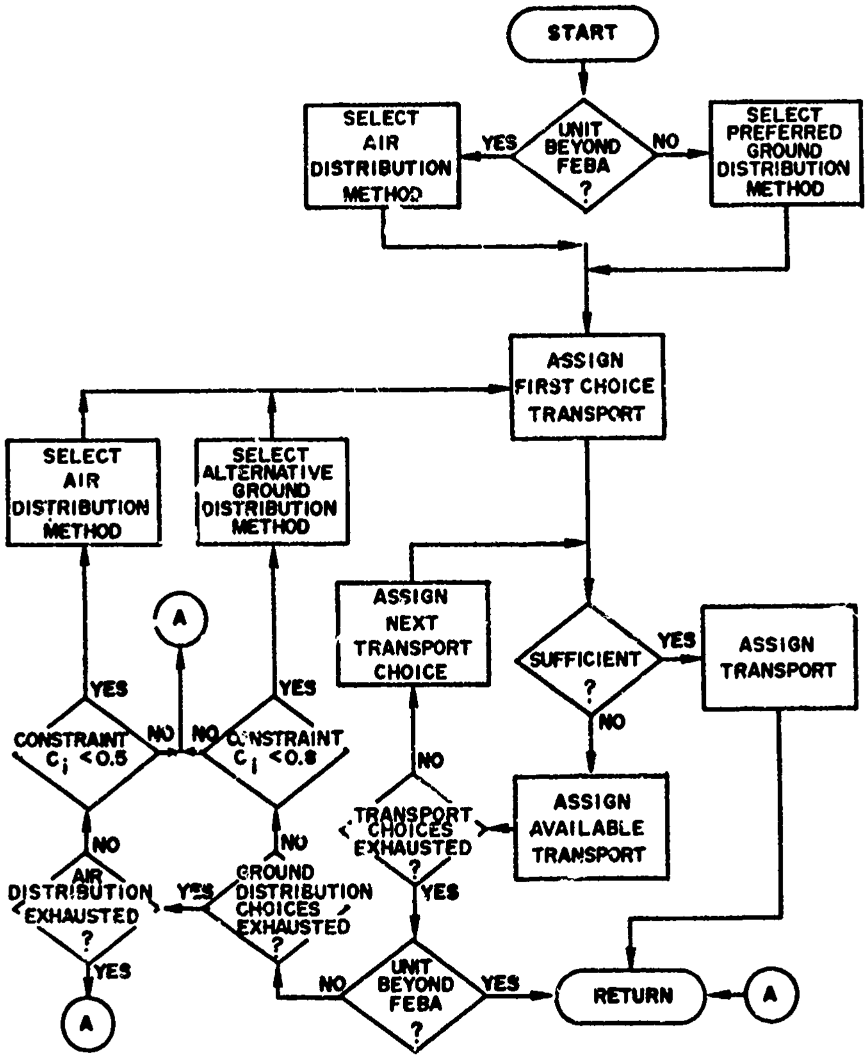

Figure 9-5. Transport Assignment Algorithm

As currently programmed, the second ground distribution method is attempted if $c_i < 0.8$, and air transport is attempted if $c_i < 0.5$. These values are judgmentally set and should be subject to sensitivity testing.

(b) Essential Calculations:

1. General. The transportation algorithm is essentially a logical check and decision process with minimal calculation involved. The necessary calculations are those used to determine the extent to which available transportation can move the requested amount of supplies. This is accomplished by comparing the weight and volume of the order to weight and volume capacities of the available transport vehicles and either assigning as much of the available capacity as is required to carry the full order or assigning the total available transport capacity to carry as much of the order as is possible. Within the process, a check is also made to verify that the supply point under unit distribution has sufficient stocks to fill the order. If not, all available stocks are used.

2. Weights and Volumes. The weight and volume of the order quantity are calculated by multiplying the order quantity by unit bulk weights and volumes contained in the constant data base. Similarly, weight and volume transport capacities are calculated by multiplying the number of currently available (within the requesting unit for supply point distribution or at the supply point for unit distribution) vehicles by the bulk weight and volume capacities per vehicle, also in the constant data base. If the weight and volume capacities of available transport equal or exceed the weight and volume of the order, the order can be transported, and a percentage of the available transport vehicles is assigned using Equation 9-11:

$$v_t = v_a \cdot p_t = v_a \cdot \max(p_{wt}, p_{vt}) \qquad (9\text{-}11)$$

where:

v_t = number of vehicles assigned to the order

v_a = number of vehicles available in the unit

p_t = $\max(p_{wt}, p_{vt})$, the percentage of transport capacity assigned for the order

p_{wt} = ratio of weight of the order to weight transport capacity

p_{vt} = ratio of volume of the order to volume of the transport capacity.

If the weight or volume transport capacity is exceeded by the weight or volume of the order, all available vehicles are assigned, and a percentage of the order is filled as calculated by Equation 9-12:

$$c_f = c_o \cdot p_c = c_o \cdot \min(p_{wc}, p_{vc}) \qquad (9\text{-}12)$$

where:

c_f = amount of the ordered item to be transported by the assigned vehicles

c_o = amount of the order outstanding up to this assignment of vehicles

p_c = $\min(p_{wc}, p_{vc})$, the percent of the order to be filled

p_{wc} = ratio of available transport weight capacity to weight of outstanding amount of order

p_{vc} = ratio of available transport volume capacity to volume of outstanding amount of order.

As an order, or part of an order is filled, records on the Supply Action File (discussed in Subparagraph (4) below) are generated, and the assigned vehicles are removed from the Unit Status File of the unit providing them, thus becoming unavailable for assignment until the supply action is completed. If unit distribution is involved, the amount of materiel shipped is removed from the status file of the supply point. If this should exceed stocks on hand at the supply point, only the amount on hand is shipped; and the amount of transport involved in adjusted accordingly.

(4) Supply Actions. The Supply Action File is used to keep track of the status of all supply actions. As transport capacity is assigned to an order, two entries (records) are initialized on this file; one to keep track of the vehicles and one to keep track of the materiel (or personnel) being transported. Each record on the Supply Action File contains six essential values:

- t_c, game time that the record is due to be updated
- u_1, identification of the unit generating the order
- u_2, identification of the unit filling the order
- i, equipment item code, identifying the item involved in the action (vehicle or consumable)

- n_i, quantity of item i involved in the action
- s, status flag for the supply action.

At the beginning of each Combat Service Support Model review cycle, all existing records on the file are updated. The actions taken in initiating and updating these records depend upon whether unit distribution or supply point distribution is involved and are explained below.

(a) Unit Distribution Supply Actions:

1. Initiation. To initiate a unit distribution supply action record, the unit identifications u_1 and u_2; equipment item code, i; and quantity of item, n_i; are set. The quantity involved is that established by the transportation assignment algorithm discussed in Paragraph 3a(3). As discussed in Paragraph 3a(3), these quantities are subtracted from the Unit Status File of the providing unit. (For an initial supply point, the quantity of materiel or personnel is actually added to the supply point Unit Status File. Thus, no limits on flow of supplies into the force are simulated, and this unit maintains a count of materiel and personnel entered into the force simulated from external sources.) The time that the record is due to be updated, t_e, is calculated by adding transit time for the vehicle involved to the current game time. Transit time is calculated based on the distance between units and the mobility characteristics of the vehicle as described in Paragraph 3a(2). Briefly, it assumes the average (over terrain types) limiting vehicle speed under prevailing light and weather conditions and a straight line route between units. The action status flag is set to 1, indicating the update action to be taken at time, t_e, is that for arrival of unit distribution at the receiving unit.

2. Arrival at Receiving Unit. When a time, t_e, less than or equal to current game time is sensed during the update cycle and an action status flag of 1 is found, the arrival at the receiving unit is treated. The action file record containing materiel is closed after the item quantity, n_i, is added to the unit's amount of the item on hand in bulk. The action file record containing vehicles is updated by adding transit time and bulk overhead time for unit distribution to t_e and setting the action status flag to 3, indicating the time at which vehicles will be returned to the supply point after offloading and the return trip.

3. Return to Supply Point. When scheduled action time, t_e, is exceeded by current review time, and an action status flag of 3 is found, the vehicles are returned to the status file of the supply point, becoming available for reassignment; and the supply action record is removed.

(b) Supply Point Distribution Actions:

1. Initiation. Supply point distribution action records are initiated similarly to unit distribution records. For each action, two records are initiated; one for the vehicles and one for the materiel (or personnel). The appropriate unit identifications, equipment item code, equipment quantity, and times are set. In this case, no check is made of the amount of materiel available at the supply point. The number of vehicles is subtracted from the Unit Status File of the providing unit, in this case the unit initiating the requirement. The action status flag is set to 2, indicating the arrival at the supply point as the next event.

2. Arrival at Supply Point. When t_e is exceeded by review time and an action flag of 2 is found, actions upon arrival at the supply point are treated by updating the supply action record. The transit time and bulk overhead time for loading are added to t_e to obtain the new event time. Both records are turned around by inserting the new event time and an action flag of 4. Additionally, the quantity of materiel to be returned to the requesting unit is subtracted from the unit status file of the supply point. If the supply point has insufficient stocks, all available stocks are taken, and the quantity on the materiel action record is reduced accordingly. (As discussed in Paragraph 3a(4)(a), there is no limit on initial supply points, and quantities are added to Unit Status Files.)

3. Return to Requesting Unit. When t_e is exceeded by game time, and the action status flag is 4, the return trip to the requesting unit is complete. Quantities of vehicles are returned to the Unit Status File, becoming available for reassignment; quantities of materiel received are added to the units' on hand bulk quantities; and the supply action records are removed.

b. Processing of Personnel and Major End Items:

(1) The processing which occurs in determining the quantities of major end items and personnel to be supplied to the various units is displayed in Figure 9-6. The flow can be broken into two logical processes: determination of replacement quantities and creation of supply actions.

(2) As losses of personnel and major end items are calculated for each unit, they are accumulated for each unit group. The available resources are first compared with the requirements of the front line maneuver units. If available resources are sufficient to meet their requirements, then the front line units are allotted enough replacements to satisfy their needs. All artillery units and any other maneuver units are then examined. If their requirements can also be met, then all remaining units are examined.

(a) When sufficient quantities of a major end item or personnel are not available to satisfy the total requirements of a unit group, the quantity available is prorated to the units based on the units' losses. As

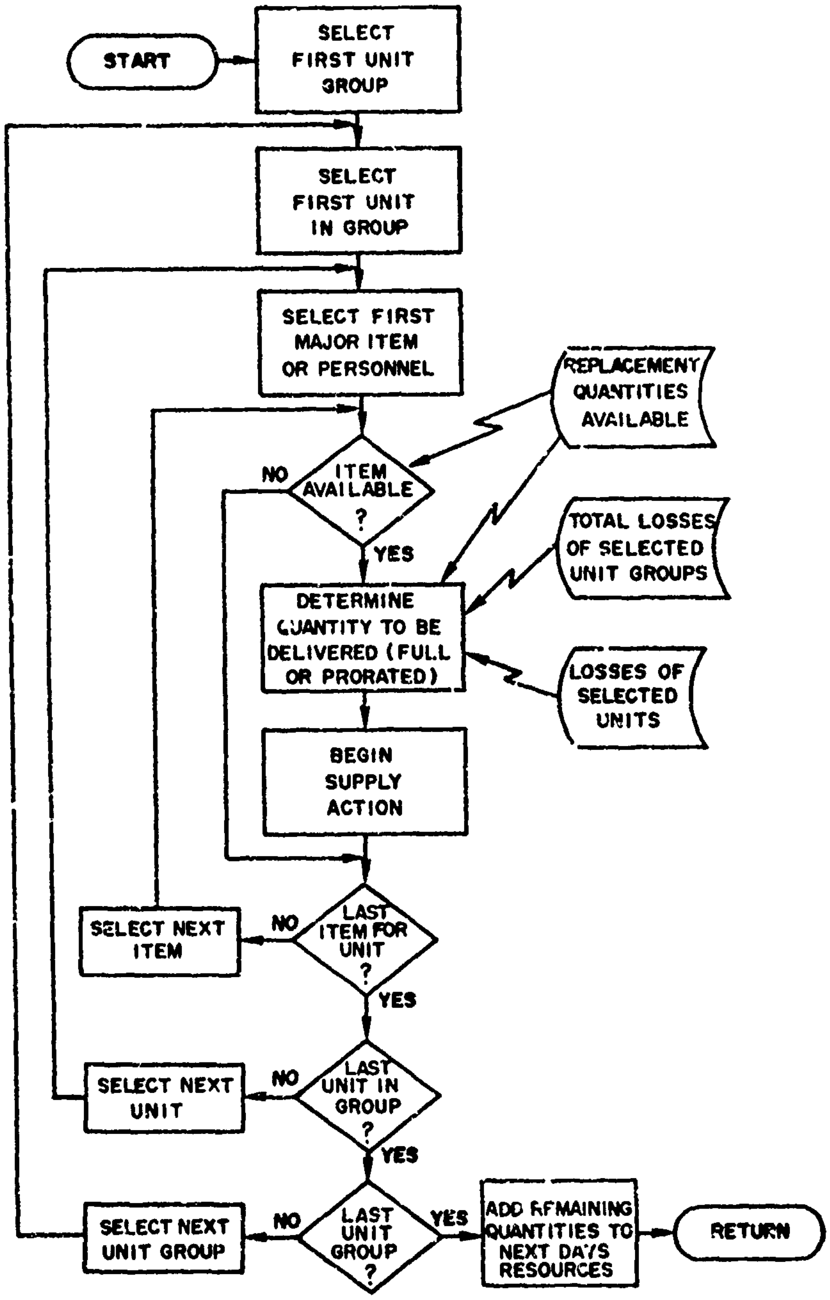

Figure 9-6. Processing of Major End Items and Personnel

an example, if 10 tanks are available for resupply but a need exists for 20 (6 to one unit and 14 to a second unit), then the first unit would receive three and the second unit would receive seven. If after the front line maneuver units' requirements are met, no resources are available, the remaining unit groups are not allocated replenishment or replacements. Similarly, if the second unit group's requirements cannot be met, then the third unit does not receive replenishment or replacements.

(b) The number of personnel and quantity of major end items of equipment that will be available to the division for resupply on each day of combat are specified pregame for each major end item. Items not used on a given day are added to the next day's available quantity.

(3) Supply Actions. The Supply Action File is used to maintain the status of all supply actions. As personnel and major end items are allocated, an entry (record) is initialized on this file. Six essential values are contained on the Supply Action File record. These values were delineated in Paragraph 3b(4). The status flag for this action is set equal to 5. The time that the record is due to be updated is set equal to current time plus the time required for the item or its transporter to travel from the division rear services area to the receiving unit. The rate of movement is the road movement rate of the major end item if it is self-propelled; otherwise, the rate is that of the transporter. When the replacements reach the receiving unit, they are immediately added to the unit's status file.

CHAPTER 10

AIRMOBILE MODEL

1. MILITARY ACTIVITIES REPRESENTED:

a. General:

(1) The Airmobile Model permits the simulation of a variety of airmobile operations; however, the model is considered to be primarily an execution model as distinguished from a planning model. The model relies upon the gaming staff for most of the general planning and decision-making prior to the simulation of an airmobile operation, and these plans are implemented through a set of gamer orders. The model may, however, be used for limited planning purposes.

(2) The principal military activities represented by the Airmobile Model include limited planning based on gamer input, staging and loading of the airmobile task force, air movement to and from the objective area, attrition of the airmobile column in flight, suppression of enemy air defenses by escort helicopters, refueling and rearming of aircraft, release of aircraft upon completion of mission, and the return of the aircraft to the bases for reassignment. These activities are discussed in detail in this chapter. Other activities inherent to airmobile operations which are not discussed herein are simulated by other models. Examples of such related activities are flight reconnaissance (simulated by the INC Model), delivery of preparatory fires (simulated by the Area Fire and Air Ground Engagement Models), employment of the airmobile task force at the objective (simulated by the Ground Combat Model), and resupply of the task force (simulated by the CSS Model). The model will simulate execution of the gamer's plan as ordered by DSL but will not make decisions changing that plan to reflect new information or enemy responses. Conditionals keyed to other activities may be specified. If resources to execute the airmobile operation become inadequate through either attrition or consumption during the operation, the model will halt the simulation.

b. Planning. Most of the planning, coordination, and preliminary activities for an airmobile operation are performed by the gamers. Information upon which to base this planning is available at the start of the game from the Game Directive and the Game Plan. Additionally, the information upon which to base this planning may be obtained prior to the start of a period from the Force Status and the Intelligence Reports from the preceding game period. With information available, the gamers execute the following activities prior to simulation of the airmobile operation.

(1) Designate the Airmobile Task Force. The required composition of the task force to be lifted is determined by the gamers. The task force is composed of basic units defined in the TOE data load which do not contain

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equipment items incapable of being airlifted. The task force for a given airmobile operation may be separated into smaller resolution forces to permit the use of multiple landing zones, staging areas, pickup zones, flight corridors, lift forces, or sequential arrival times. Each resolution force will be treated individually within the model.

(2) Select the Objectives and Designate the Landing Zone. The objective (or objectives) of the airmobile operation is determined by the gamers. Landing zones are designated by coordinates for each resolution force. Intermediate landing zones may be designated in addition to the final landing zone if a series of lift operations is desired.

(3) Establish Airmobile Lift Timing. The time for each lift operation is to be designated. Either the time to arrive at the landing zone or the time to begin the move may be specified by the gamers. The other times are calculated within the model.

(4) Select Staging Areas and Pickup Points. Staging areas or pickup points are determined for each resolution force. These locations are described by coordinates.

(5) Select Flight Corridor. The flight path for each lift operation is to be described by the coordinates of the starting and ending points (pickup and landing zones) and up to three intermediate coordinate locations. The model will route the resolution airmobile force from the starting coordinates over each intermediate point to the ending coordinates.

(6) Designate Forward Refueling and Rearming Areas. Adequate facilities must be provided to refuel transport and escort aircraft and to rearm escort aircraft within the forward area. This is accomplished automatically within the model if forward refueling and rearming units are defined by the pregame data load and are positioned in the proper areas during the game by gamer orders.

(7) Specify Transport and Escort Aircraft Mix. Up to 10 unique mixes of transport and/or escort aircraft types, escort aircraft munition loads, aircraft fuel loads, and aircraft crew can be defined for each force (Red, Blue) in the pregame data load. The optimal mix for transporting each resolution force within the airmobile task force is determined by the gamers.

(8) Develop the Fire Support Plan. Preparatory fire support is planned prior to the airmobile operation. Artillery, missiles, attack helicopter, and close air support may be utilized. The fire missions will be ordered by the gamers and simulated by the Area Fire and Air Ground Engagement Models.

(9) Designate Lift Force. The preferred aviation units to provide the airlift and escort resources are designated. Those units are directed by DSL orders to provide direct support to the airmobile task force. The

model will attempt first to allocate required resources from units in direct support of the airmobile task force before selecting other units. The gamers should ensure that adequate resources (aircraft, crews, munitions, and fuel) are available within the force and, preferably, at the unit designated to support the operation.

(10) Determine the Number of Aircraft or Trips. The number of transport aircraft of the type specified by the selected mix is determined. The number may be specified explicitly by gamer orders or implicitly from the desired number of trips which may alternatively be stated in the gamer orders. If the number of trips is specified, the model will calculate the number of aircraft which would be required to transport the resolution force utilizing the weight, volume, and capacity data contained on the CSS data file. The number of escort aircraft of the type specified by the selected mix is determined by the gamers if escorts are required.

(11) Prepare Gamer Orders. The set of gamer (DSL) orders required to implement the plan is then prepared. The orders are described in Volume IV, DIVWAG Users Manual, and in subsequent sections of this chapter.

c. Staging. The three steps of the staging phase are described below.

(1) Assembling the Task Force. The assembling and organizing of the airmobile task force is under gamer control, through the use of conventional DSL orders. All elements of the force are ordered to one or more staging areas or pickup points by means of MOVE orders. Elements of the force may be combined or separated as desired by use of the JOIN and DETACH orders. The elements must be composed of basic units defined in the task organization and with a unit type designator (UTD) in the TOE load. Elements are combined into a single task force unit or into individual resolution airmobile task force units as desired. The task force should contain only equipment which can be airlifted. The task force may not contain organic aircraft. The execution of the JOIN and DETACH orders is performed external to the Airmobile Model in the same manner as any other order of that type.

(2) Allocating Lift Resources:

(a) ACCEPT TRANSPORT Order. To accomplish airlift of a ground combat element one of two alternative forms of a DSL ACCEPT TRANSPORT order is employed. The first alternative form is:

ACCEPT TRANSPORT MIX _____, NUMBER OF AIRCRAFT _____,
NUMBER OF ESCORTS _____, AT TIME _____.

The second alternative form is:

ACCEPT TRANSPORT MIX _____, NUMBER OF TRIPS _____,
NUMBER OF ESCORTS _____, AT TIME _____.

1. The number of aircraft in the first alternative refers to transport aircraft. The transport mix refers to the index number in the table of up to 10 mixes per force provided in the constant data load. Each mix is defined in terms of:

- Transport aircraft type
- Fuel load per transport aircraft
- Crew per transport aircraft
- Escort aircraft type
- Fuel load per escort aircraft
- Crew per escort aircraft
- Up to three escort munition types, with quantities per escort aircraft.

2. The AT TIME ____ and NUMBER OF ESCORTS____ modifiers are optional. If no escorts are required, that modifier clause is omitted. If the indicated mix includes escort aircraft descriptions, but escorts are not requested in the ACCEPT TRANSPORT order, the escort aircraft portion of the mix description is disregarded. The AT TIME modifier causes the aircraft to arrive and land at the pickup zone at the time specified if the aircraft are capable of flying from their bases to that point in the allocated time. If no time is specified or the specified time cannot be met, the aircraft will arrive at the pickup zone as soon as they are capable of flying that distance.

3. If the second alternative is used, specifying the number of trips instead of the number of aircraft, the model calculates the required number of aircraft, based on the lift capacity of the transport aircraft and the weight and volume of the personnel and all equipment in the unit to be lifted, at the time the ACCEPT TRANSPORT order is initiated, using Combat Service Support Model constant data input. The model does not attempt to allow for attrition when calculating the required number of aircraft.

(b) Order Execution:

1. The model executes the order by first selecting the optimal source of both transport and escort aircraft. It initially attempts to locate an airbase which can satisfy the requirements for both transport and escort aircraft with their associated resources. Aircraft are obtained from the nearest friendly airbase containing needed resources, according to the designated support relationship of the airbase to the unit to be lifted. Support categories are chosen in the following order of preference:

- Direct support to the airmobile task force or any superior unit

- General support

- Direct support to other units.

2. If a single base cannot supply all resources, then the model searches for an optimal source of each type separately (i.e., transport separate from escort). An airbase will not be selected as a source of escorts, transports, or both unless it can provide the full quantity of aircraft, fuel, crew, and munitions. If the model is unable to allocate the required resources, the period is terminated. If the escort aircraft are from a different base than the transports, the model simulates the flight of the escort aircraft directly to the selected transport base where the two aircraft units are consolidated. The aircraft unit flies from the transport airbase directly to the location of the unit receiving the ACCEPT TRANSPORT order. Fuel is consumed by the aircraft while flying from the bases to the pickup zone.

(c) Penetration Flights. If the consolidated air unit must penetrate enemy airspace to reach the pickup zone, the flight is routed first to a safe point as defined by the Air Ground Engagement Model (Chapter 6). It is then passed to the in-flight attrition segment which simulates the flight from safe point to the pickup zone while being attrited by air defense fire. A penetration flight is defined as one in which the pickup zone lies across a line perpendicular to the battlefield slope and passing along the forward edge of the most forward enemy front line maneuver battalion.

(3) Forming Airmobile Task Force and Lift Resources. The model automatically joins the aircraft unit into the unit receiving the ACCEPT TRANSPORT order. The aircraft, crews, fuel, and munitions remain with that unit until released by gamer orders. They are attrited by area fire and air attacks along with the remainder of the unit. A unit cannot have more than one ACCEPT TRANSPORT order active at any time. It must release previously assigned transport before accepting any additional transport resources.

d. Loading and Air Movement. Loading and air movement of the airmobile task force or of each resolution airmobile force (if smaller units are assembled) is conducted according to the air movement plan, as expressed by gamer prepared DSL orders of the form:

AIRMOBILE ASSAULT TO $X_1 - Y_1$, $X_2 - Y_2$,
$X_3 - Y_3$, $X_4 - Y_4$, AT TIME _____.

The AT TIME modifier is optional. The airmobile element to be lifted must have been previously allocated aircraft, by an ACCEPT TRANSPORT order as described in the preceding paragraph. This DSL order causes the transport aircraft to be loaded to their maximum capacities and with the escorts, if any, to fly from the current location of the element receiving the order to the last coordinate listed in the order, traveling over each listed intermediate coordinate. Up to three intermediate coordinate points may be specified in addition to the landing zone coordinates. The time, if specified, is the intended landing time of the first element. If additional lift trips are needed, the aircraft return as a unit along the same flight path for additional trips. Aircraft are subject to possible attrition by the in-flight attrition segment on each flight leg. If aircraft are lost en route, priority

cargoes (pregame input) are loaded first, and additional trips are scheduled in subsequent flight legs. Aircraft units are sent for refueling and rearming between trips if the remaining fuel is insufficient for one more round trip plus 30 minutes to spare, or if the quantity of air munitions of any type is less than 50 percent of initial load. On landing, the lifted element is unloaded. If more than one lift is involved for any element, between unloading of the first and last lifts, the unloaded portion of the force can execute any DSL order except JOIN, DETACH, AIRMOBILE ASSAULT, or RELEASE TRANSPORT. When the entire element is unloaded and assembled, this restriction ceases. Air movement is assumed to occur at nap-of-the-earth altitude. Flight speed is established as the cruise speed of the slowest aircraft in the flight.

e. Release of Aircraft. Upon completion of the airlifting of any airmobile element, the aircraft assigned to that task, including escorts, if any, may be released to return to their respective airbases for maintenance, repairs, and reassignment. If not released, the aircraft remain on the ground with the lifted unit and can be used for subsequent air movement. The release of air transport may be accomplished by a gamer DSL order of the form:

RELEASE TRANSPORT.

This order must be provided to a unit which previously received an ACCEPT TRANSPORT order. This order will cause the model to remove previously accepted aircraft with their crews, fuel, and munitions from the unit. A new unit is formed containing those elements. The model then simulates the flight of that unit back to the airbase or airbases from which the aircraft came. If the unit is in enemy airspace, as defined in Paragraph c(2)(c) above, the first leg of the returning flight path is flown from the starting point to the safe point as described in the Air Ground Engagement Model (Chapter 6, Volume III). Upon reaching the safe point, a check is made to see if sufficient fuel is on board to return to the airbase of the transport aircraft. If fuel is needed, the unit is passed to the control of the forward area refuel and rearm segment for refueling prior to returning to the base. Otherwise, the flight returns directly to the transport base. If the escort aircraft came from a different base, they continue to their base of origin. Aircraft are restored into the resources of their airbase after appropriate time delays, including times for repairs according to damage categories. Those delay times and their application are described in Chapter 6.

f. Refueling and Rearming. When refueling or rearming of a unit of aircraft is required, the refueling and rearming segment takes over control of the unit. It selects the nearest forward area refuel and rearm (FARR) area in the highest support category which is neither moving nor under attack. The support categories are those listed in Paragraph c(2)(b) above. The model simulates the flight of the aircraft as a unit to the selected point. The unit may then be held in a queue until service capacity is available. Service is on a first-come first-served basis. When capacity is available, the unit lands at the FARR area. Time for refueling and rearming then depends on the requirements of the aircraft and the available capacity of the facility.

The aircraft within the unit are serviced individually, first refueled and then rearmed if necessary. If the capacity is being fully utilized, the individual aircraft will remain in a refueling queue and then a rearming queue until their appropriate turns to be servied. The number of refuel and rearm points at each FARR area is predetermined by the TOE constant data load. Each FARR area must be a resolution unit composed of TOE defined basic units. The support relationships are declared in the task organization but may be altered by DSL orders. The service rates of the rearming points are specified in the constant data load. After all aircraft have been serviced the aircraft unit is flown to a location designated by the segment processing the unit's current order, and the unit is then returned to the control of that segment.

g. In-flight Attrition. Whenever an airmobile flight enters hostile air space, the flight is subject to possible attrition by enemy air defense weapons. This attrition is simulated within the model by considering the flight path in relatively short segments. Only currently undestroyed and unsuppressed air defense weapons within range and having line of sight to a flight segment are able to cause attrition on that flight segment. Line of sight is determined from flight altitude and terrain masking at the weapon, as calculated from terrain elevation input data. Flight altitude varies linearly from a nap-of-the-earth elevation over the terrain at the ends of the flight leg. When the flight first enters range and line of sight of the first enemy air-defense-capable unit (ADCU), a delay is imposed for probable time for the ADCU to detect the flight. [illegible]lays are also imposed for weapon reaction, and for the time of flight of any projectiles that are fired at the flight. Detailed weapon characteristics are used to determine whether the AD gun or missile can fire and how many projectiles will be fired. For projectiles to intercept the flight, the flight must remain in range and line of sight throughout that time. Only the effects of projectiles that can intercept the flight are considered for attrition. Aiming error and round-to-round dispersion are based on slant range to the midpoint of the flight segment and are used to determine hit probability on presented area of the aircraft at the aspect angle to the midpoint. Kill probabilities are determined by considering the aircraft vulnerable area, at the midpoint aspect angle, for the velocity of the AD projectile impacting. Good communications are assumed to exist between all air defense weapons within a given ADCU, so that time delays are not reimposed unrealistically. Communications are also assumed between different ADCUs, again to prevent unrealistic reimposition of detection times. When the flight enters range or line of sight of a second ADCU while a first ADCU is still firing no detection delay is assessed, although other delays may be assessed as described in Paragraph 3e. Weapons within an ADCU are considered to be located near the perimenter of the unit for range determinations. No changes in the flight path are automatically made to evade air defense fires.

h. Air Defense Weapon Suppression. The employment of escort aircraft to suppress ADCUs which attempt to engage the airmobile column is simulated by the in-flight attrition submodel. Additionally, air defense weapons are suppressed by artillery, TACAIR, and other attack helicopters resulting from

the effects of the Area Fire and Air Ground Engagement Models. The in-flight attrition submodel, in connection with the activity suppression submodel, simulates the suppressive effects of such fires. The suppressive effects against an ADCU are reflected in the ability of that ADCU to attrite the airmobile column and are simulated by means of a suppression duration time applied for each attack of an ADCU. The suppresion duration delay times are specified in the contant data input for the activity suppression submodel. Escorts are assumed to remain close to the transport aircraft they are escorting. Escorts are not permitted to divert more than a fixed distance from the flight path centerline in order to attack an ADCU. That distance is specified in the Airmobile Model constant data input. If the ADCU is destroyed or suppressed, it is assumed not to be firing and is not subject to further attack by escort aircraft. If the airmobile flight being escorted has passed beyond the point on its flight path nearest to the center of the ADCU, the ADCU is not engaged by escorts. The model accounts for the escorts engaging ADCUs at all times. If all escorts to an element are currently engaging targets, any additional ADCUs cannot be attacked by escorts. If escorts are available and the ADCU is within the designated escort divert limit of the flight path, escorts are dispatched in pairs at the time the ADCU begins to fire on the airmobile element being escorted. If an ADCU located beyond escort divert limit fires on the element, a request is sent for quick-response suppressive fires from TACAIR or ground-based artillery. While such fires may not be delivered in time to benefit this flight, they may benefit any following flights.

2. DESIGN OF THE AIRMOBILE MODEL:

a. Approach. A major objective in design of the Airmobile Model is to keep the model as general as possible, conforming to basic airmobile doctrine and current practice rather than to specific situational or type concepts. This objective precludes the application of automatic decision logic or other modeling sophistications that might be considered. Instead, heavy reliance is placed upon gaming personnel to specifically plan and describe each airmobile operation through the use of DSL orders. Reliance on gamer control is necessary, not only to achieve generality of the model, but also because doctrine is either incomplete or highly flexible in many specific situations. Furthermore, in a single game, only a limited number of airmobile operations is likely to be performed, and their anticipated impact on game results justifies a high degree of gamer control. Another objective of the design is to restrict modeling to those aspects considered essential to realistic gaming of airmobile operations, on the grounds that other features may be added at a later time, if found necessary.

b. Constituent Submodels. The Airmobile Model consists of five submodels. These submodels, each of which constitutes an independent program segment, are:

- Accept Transport
- Airmobile Assault
- Release Transport
- Refuel and Rearm
- In-flight Attrition

c. Macroflow. The flow between submodels is sequential, as shown in Figure 10-1.

d. Connection with Other DIVWAG Models. Simulation of an airmobile operation requires utilization of a large portion of the overall DIVWAG Model. The only major DIVWAG component connected directly to the Airmobile Model is the Intelligence and Control Model. The Intelligence and Control Model, in turn, interacts with the Area Fire and Air Ground Engagement Models, causing fire support to be automatically applied as required. Other important parts of the DIVWAG system necessary to simulation of an airmobile operation are brought into play by indirect connections, primarily represented by coordinated DSL orders.

(1) Intelligence and Control Model. Calls to the Intelligence and Control Model are made by the Airmobile Model in two circumstances. One circumstance is at the beginning of each air movement flight leg. The purpose of this call is to subject the flight to possible acquisition by enemy air defense radars. The second circumstance is when an ADCU fires at an airmobile element from a location beyond the escort aircraft divert limit. In this case, this call is a request for quick-response fire support against this ADCU. If resources are available, the result is response from either the Air Ground Engagement Model (TACAIR or attack helicopters) or the Area Fire Model (ground-based artillery).

(2) Indirect Connections. Coordinated DSL orders are likely to be employed to activate the Intelligence and Control Model for preparatory reconnaissance flights, the Area Fire and Air Ground Engagement Models for preparatory fires, and the Ground Combat Model for task force employment at the objective. Data placed in the Unit Status File of an ADCU by the activity suppression submodel (see Chapter 5) are used to determine whether the ADCU is suppressed by TACAIR or ground-based artillery. Line of sight determination for in-flight attrition is made by the environment submodel. The Combat Service Support Model resupplies the airbases, airmobile forces, and the ADCUs. It replaces destroyed aircraft, lost personnel, and expended fuel and ammunition.

3. SUBMODEL SPECIFICATIONS:

a. Accept Transport (Segment 1):

(1) Purpose. The accept transport segment is executed in response to a DSL order of the form:

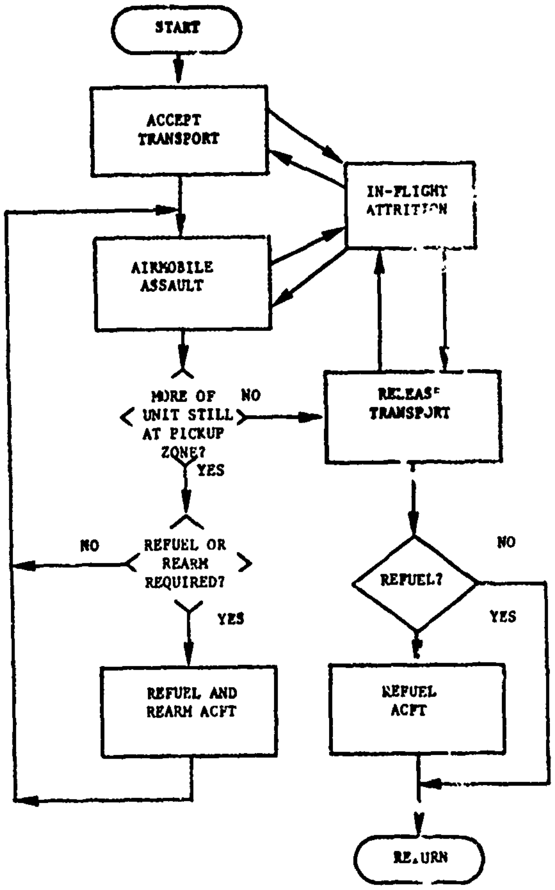

Figure 10-1. Macroflow of Airmobile Operation

ACCEPT TRANSPORT MIX _____ NUMBER OF
AIRCRAFT _____ NUMBER OF ESCORTS _____
AT TIME _____.

or:

ACCEPT TRANSPORT MIX _____ NUMBER OF
TRIPS _____ NUMBER OF ESCORTS _____
AT TIME _____.

Such an order is given to an airmobile task force or to each of a group of smaller resolution airmobile forces at some time prior to its AIRMOBILE ASSAULT order. This segment locates available aircraft of the indicated types; loads them with the appropriate munition mix, fuel and crew; and moves them to the pickup zone at the indicated time. The aircraft remain with that task force until explicitly released by a RELEASE TRANSPORT order. The aircraft may be used for a series of airmobile operations.

(2) Operation. The macroflow of this segment is shown in Figure 10-2. The following steps are performed:

(a) The DSL order is converted to an automatic event by Subroutine AIRCNTRL. The event is passed to the Airmobile Model where it is channeled to Subroutine ACCEPT1. The unit receiving the ACCEPT TRANSPORT order has thus simulated a request for air transport support, and the unit then proceeds to execute its next DSL order in the normal fashion.

(b) Subroutine ACCEPT1 processes the request and schedules the departure of the air units and their flights to the requesting unit in the following sequence of operations.

1. The mix type specified in the DSL order is an index to the mix table on the airmobile data file. That table is examined to determine the types of aircraft (escort and transport) and munitions, and the quantities of fuel, munitions, and personnel per aircraft.

2. If the number of transport aircraft was not specified in the DSL order it is computed by totaling the weight and volume of all personnel in the requesting unit and all equipment excluding aircraft, Class IIIA (fuel), and aircraft munitions. The weights and volumes are obtained from the CSS Model data file. The capacity of the transport aircraft is also obtained from that file. The number of transport aircraft is calculated using the following formula:

$$\text{Number of Transport Aircraft} = \frac{\text{MAX}\left(\dfrac{W_u}{W_a}, \dfrac{V_u}{V_a}\right)}{N_T} \qquad (10\text{-}1)$$

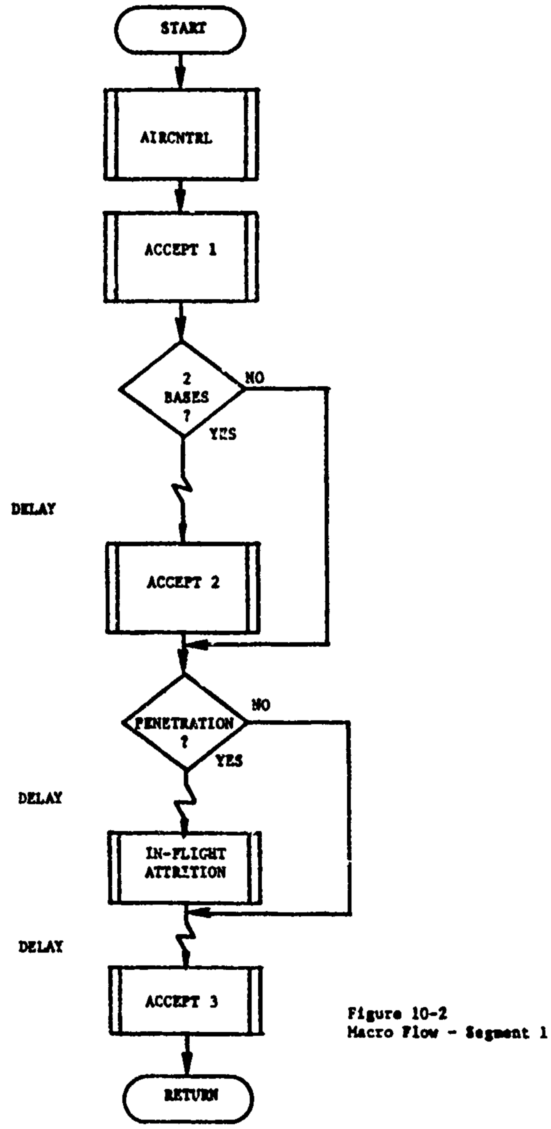

Figure 10-2. Macroflow of Accept Transport - Segment 1

where:

W_u is the weight of the unit's equipment and personnel

W_a is the weight capacity of the transport aircraft type

V_u is the volume of the unit's equipment and personnel

V_a is the volume capacity of the transport aircraft type

N_T is the number of trips requested

The number of transport aircraft is rounded up to the next highest integral value.

3. The list of friendly airbases is assembled and sorted into three categories: direct support to the requesting unit; general support; direct support to another unit. The list is further sorted within each category in order of proximity to the requesting unit.

4. The list is searched once to select the airbase which can supply all escorts, transports, fuel, munitions, and personnel ranking highest on the sorted list. If no airbase satisfies the requirement, the list is searched again to select two bases which can supply all escort and all transport resources, respectively. If all resources cannot be found, a message is printed; and the game period is terminated.

5. Mission units are created at the base or bases. These units are temporary resolution units which are loaded with the aircraft, crews, fuel, and munitions provided from each base. The mission units have locations, unit identifications, and unit type designations and are handled within the model as any other resolution unit with two exceptions: (1) they cannot receive DSL orders, and (2) they occupy no physical area.

6. Subroutine PENTRATE is called to determine if the flight is to penetrate enemy airspace. A penetration will occur if the requesting unit is located across a line perpendicular to the battlefield slope and passing along the forward edge of the most forward enemy maneuver battalion. If a penetration is to occur, this subroutine also returns the coordinates of the point along that line which is nearest to the requesting unit. The flight path will be adjusted to fly over that point. The point is called the safe point.

7. The flight speeds and fuel consumption rates of the aircraft are obtained from the Air Ground Engagement Model and Movement Model data files, respectively.

8. The total time required to combine the two mission units (if two bases have been selected) and fly to the requesting unit is calculated based upon the flight path distances and the flights speeds. This time is compared to the arrival time designated in the DSL order to determine the

time that the mission units will depart the airbases. If a time is not specified in the order, the departure is scheduled to begin immediately.

9. An event is scheduled in the automatic event table to simulate the flight of the escort mission unit to the transport aircraft base if two bases were selected. That event will be processed by Subroutine ACCEPT2. The escort mission unit is assumed to fly along a straight line from its base to the transport base.

10. The event to simulate the flight of the combined mission unit to the safe point is scheduled at this time if a penetration is to occur. The control will at that time be passed to the in-flight attrition segment which will simulate the flight from the safe point to the requesting unit and then return Control to Subroutine ACCEPT3.

11. If no penetration is to occur, the event to fly the mission unit to the requesting unit is scheduled at this time. Control goes to Subroutine ACCEPT3 at the appropriate game time.

12. The flight speed of the combined unit is equal to the speed of the transport aircraft. The speeds are obtained from the Air Ground Engagement Model data file for the current weather and light conditions.

(c) Subroutine ACCEPT2 is executed in response to an automatic event scheduled by Subroutine ACCEPT1. The time of this event was established in ACCEPT1 as the time at which the transport mission unit and escort mission unit are to be consolidated into a single mission unit for the flight to the requesting unit. The following sequence of steps occurs.

1. The location of the escort mission unit is updated to that of the transport airbase. The fuel consumption for that leg was assessed in ACCEPT1. The objective point of the next flight leg is set to the coordinates of the requesting unit.

2. All fuel aircraft, and personnel in the transport mission unit are added to the escort mission unit. The transport mission unit is then eliminated.

3. Subroutine PENTRATE is called to determine if a penetration will occur while flying from the transport base to the requesting unit. If a penetration will occur, the flight is rerouted over the safe point and an event is scheduled for the arrival of the flight at that point. Control will then go to the in-flight attrition segment to simulate the flight from the safe point to the requesting unit, after which control will go to Subroutine ACCEPT3.

4. If no penetration is to occur, an event to process the arrival of the mission unit at this requesting unit by Subroutine ACCEPT3 is scheduled in the automatic event table.

5. Fuel consumption for the next flight leg is assessed using the consumption rates listed in the Movement Model constant data file.

(d) Subroutine ACCEPT3 processes the consolidation of the mission unit into the requesting unit. It is executed in response to an event scheduled by (1) the in-flight attrition segment, if the flight involved a penetration; (2) Subroutine ACCEPT1, if there was no penetration and all aircraft came from the same base; or (3) Subroutine ACCEPT2, if there was no penetration and the aircraft came from two different bases. The following sequence of operations is performed.

1. All equipment and personnel in the mission unit are transferred to the requesting unit.

2. An array is established on the requesting unit's status file indicating the types of aircraft and munitions which it has received and the identifications of the airbase or bases from which the resources were supplied. This array is used by the release segment to allow the resources to be returned to the proper bases.

3. The mission unit is dissolved and its identity is available for reuse.

b. Airmobile Assault (Segment 2):

(1) Purpose. The airmobile assault segment is executed in response to a DSL order of the form:

AIRMOBILE ASSAULT TO_____ - _____ , _____ - _____,
_____ - _____, _____ - _____ AT TIME _____.

Such an order is given to an airmobile task force to cause it to be airlifted over the coordinate points listed in the order and landed at the last coordinate point in the list. The first element is to arrive at the designated time. Up to four coordinate points can be included. This order must have been preceded at some time during the game by an ACCEPT TRANSPORT order for that task force unit. The task force unit may be any combination of basic units which have been assembled into a single unit by JOIN orders.

(2) Operation. The macroflow of this segment is shown in Figure 10-3. The following steps are performed:

(a) The DSL order is converted to an automatic event by Subroutine AIRCNTRL. The event is passed to the Airmobile Model where it is channeled to Subroutine ASSAULT1. The unit is taken out of the event cycle

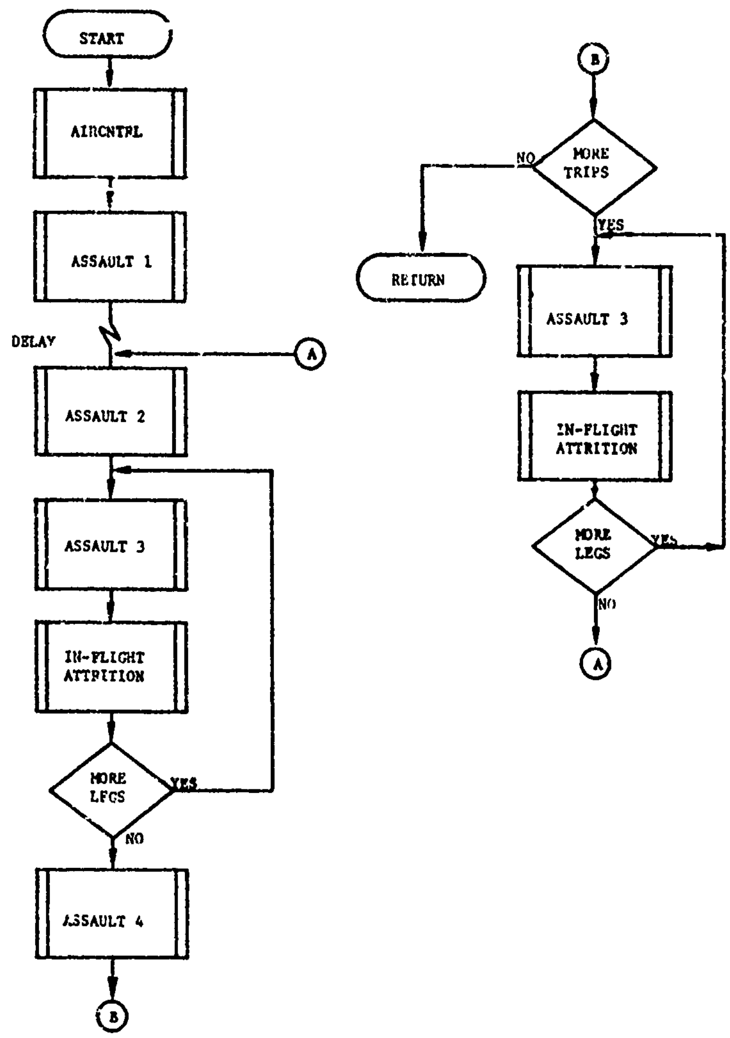

Figure 10-3. Macroflow of Airmobile Assault - Segment 2

and will not perform its next DSL order until the initial element has reached the designated landing zone.

(b) Subroutine ASSAULT1 builds the initial File 12 event description record and obtains necessary data from the appropriate data files, which are saved on the File 12 record. It also schedules the initial departure event. The following sequence of operations is performed.

1. The flight path coordinates contained in the DSL order are read in using the DSL interface routines, and the coordinates are stored on the File 12 event record.

2. The types of escort and transport aircraft which the unit has previously accepted by an ACCEPT TRANSPORT order are stored on the File 12 record.

3. The fuel consumption rates, flight speeds, and landing times are obtained from the Air Ground Engagement Model data file for each type of aircraft and are stored on the File 12 record. The flight speed is that designated for the weather and light conditions existing when the ASSAULT order is initiated.

4. The total flight time from the unit's current location, over the designated intermediate points, to the landing zone at the speed of the slowest aircraft is added to the landing time contained on the Air Ground Engagement Model data file.

5. The total time calculated in Paragraph 4 above is compared to the desired arrival time contained in the DSL order and the time of departure is scheduled. If no arrival time was specified, or the desired time cannot be accomplished due to the flight time, the depature event is scheduled immediately.

6. The departure event is scheduled by passing a File 12 record to Subroutine ASSAULT2 using the automatic event sequencing system.

(c) Subroutine ASSAULT2 processes the loading of the transport aircraft and the departure of the air unit. It performs the following sequence of operations.

1. The total cargo capacity (weight and volume) of the unit is calculated by multiplying the number of transport aircraft by the weight and volume capacities of that aircraft type which is contained on the CSS Model constant data file.

2. The amount to move is calculated by totaling both the weight and volume of all personnel and equipment contained in the unit excluding aircraft, Class IIIA, and air munitions. The weights and volumes of the items are obtained from the CSS Model constant data file.

3. The weight and volume of all equipment listed on the secondary priority equipment list are totaled in the same manner.

4. If either the weight or the volume to be moved exceeds the capacity of the transports, additional trips will be required.

5. If additional trips are not required, all equipment and personnel are loaded on the aircraft and an event is scheduled to pass control to Subroutine ASSAULT3 which controls the movement of the flight. The following steps are not performed when additional trips are not required.

6. A mission unit must be created and left at the pickup zone with all personnel and equipment which cannot be moved. If this is not the first trip, such a unit already exists. This mission unit has the same geometry and location as the unit being transported before the assualt began. It can be assessed by air and artillery fire as any other unit. It cannot execute DSL orders.

7. The aircraft are loaded with Class IIIA, munition, and crews. The fraction of the remaining first priority items to be moved on this trip is calculated by the following formula:

$$F_{A1} = \frac{W_A}{W_{u1}}, \quad F_{B1} = \frac{V_A}{V_{u1}}, \qquad (10\text{-}2)$$

$$F_1 = \text{MIN}\ (F_{A1}, F_{B1})$$

where:

F_1 is the fraction of the first priority equipment to be moved this trip

W_{u1} is the weight of all first priority equipment and personnel in the unit

W_A is the weight capacity of all transport aircraft

V_{u1} is the volume of all first priority equipment and personnel in the unit

V_A is the volume capacity of all transport aircraft.

The quantity of all such first priority items loaded on the aircraft is prorated by fraction, F_1, where F_1 does not exceed 1.0.

8. If fraction, F_1, exceeds 1.0, there is additional capacity remaining to move some of the second priority equipment. The amount loaded is prorated by fraction, F_2, where:

$$F_{A2} = \frac{W_A'}{W_{u2}} \quad , F_{B2} = \frac{V_A'}{V_{u2}}$$

$$F_2 = \mathrm{MIN}\ (F_{A2}, F_{B2}) \tag{10-3}$$

where:

F_2 is the fraction of second priority items to be moved on the trip

W_{u2} is the weight of all second priority equipment in the unit

W_A' is the remaining weight capacity of all transport aircraft after loading first priority items

V_{u2} is the volume of all second priority equipment in the unit

V_A' is the remaining volume capacity of all transport aircraft after loading first priority items.

9. An event is scheduled to pass control of the flight to Subroutine ASSAULT3 which controls the movement of the flight.

(d) Subroutine ASSAULT3 controls the movement of all airmobile assault units. It updates status, assesses fuel consumption, and schedules the following event. The functions performed are described below.

1. If this is not the initiation of a new flight, the fuel consumption is calculated for the previous leg using the rates specified on the File 12 record created by ASSAULT1. The fuel is subtracted from the unit status record of the unit being moved. The coordinates of the unit are updated to the completion of the previous flight leg.

2. The flight leg counter on the File 12 record is incremented to point to the coordinates of the end point of the next flight leg, and those coordinates are placed on the unit's status record for use by the in-flight attrition segment.

3. If the unit has not yet arrived at either the landing zone or the pickup zone (for subsequent trip loads), an automatic event is scheduled for the in-flight attrition segment. That segment will control the movement within a flight leg and pass control back to ASSAULT3 when the flight leg has been completed.

4. If the unit has arrived at the landing zone, an event is scheduled which passes control to Subroutine ASSAULT4. That subroutine controls the recomposition of the unit at the landing zone.

5. If the unit is at the pickup zone and the landing zone is in enemy territory, the subroutine determines if refueling or rearming is required. If sufficient fuel is not remaining to make another complete round trip with 30 minutes reserve, or if less than one half of the initial munition load remains, refueling and rearming is performed. The subroutine passes control to the refuel and rearm segment. After accomplishing that operation, the refueled and rearmed aircraft will be returned to the pickup zone, and control will return to Subroutine ASSAULT3.

6. If refueling or rearming is not required, an event is scheduled for control to go to Subroutine ASSAULT2, which loads the aircraft for the next trip.

7. If the unit is departing from a landing zone in friendly territory and returning for another trip load, the refuel/rearm decision process is made at that point.

8. The landing delay time placed on the File 12 record by ASSAULT1 is applied to all flights landing at both the pickup and landing zones.

(e) Subroutine ASSAULT4 controls the recomposition of the unit at the landing zone. It responds to events scheduled by ASSAULT3. This subroutine performs the following sequence of operations.

1. If this is not the first trip, all personnel and equipment are transferred from the arriving unit into the element of the unit which had previously been unloaded.

2. If this is the first trip, the unit being lifted is updated to the location of the landing zone and contains all equipment and personnel contained in the first trip.

3. The subroutine determines if the landing zone is in enemy territory by comparing the location of the center of the landing zone with the straight line FEBA approximation described in Chapter 2. If the landing zone lies across that line, the airmobile flag on the assaulting unit status record is set. This flag serves two purposes; (1) the unit will only be resupplied by aircraft within the CSS Model, and (2) the unit will

not be used for future battlefield geometry calculations. The flag may be cleared during the periodic battlefield geometry update if the FEBA has moved beyond the location of the center of the unit such that it is no longer on the enemy side of the line.

4. If additional trips are required to move elements of the unit remaining at the pickup zone, a mission unit is formed containing the aircraft, crews, Class IIIA, and air munitions remaining with the unit. That mission unit is returned to the pickup zone along the same flight path flown to the landing zone. An event is scheduled to pass control back to Subroutine ASSAULT3, which will control the flight of the mission unit.

5. After the last trip has been completed, all mission units are dissolved and the entire reconstituted unit remains in the vicinity of the landing zone with attached aircraft and associated resources.

6. When the first trip arrives at the landing zone, the resolution task force unit's identity arrives with it. The task force unit's location is updated, and it begins performing its subsequent DSL orders. The width and depth of the unit will be those appropriate for its new activity.

c. Release Transport (Segment 3):

(1) Purpose. The release transport segment is executed in response to a DSL order of the form:

RELEASE TRANSPORT.

Such an order is given only to a unit which had previously been given an ACCEPT TRANSPORT order and provided with transport support. This order allows the supporting aircraft to return to their respective bases for refueling, rearming, and reassignment.

(2) Operation. The macroflow of this segment is shown in Figure 10-4 The following steps are performed.

(a) Subroutine AIRCNTRL processes the DSL order. It creates a File 12 event record and passes it to the Airmobile Model where it is channeled to Subroutine RELEASE1. The unit receiving the order then proceeds to execute the next order in its DSL order scenario. The execution of this order does not consume any game time from the unit's planned scenario. It serves only to initiate the process described in the following paragraphs.

(b) Subroutine RELEASE1 is executed in response to the File 12 event scheduled by Subroutine AIRCNTRL lift. Its purpose is to extract the airmobile lift resources from the unit, create a mission unit, and schedule the events to return the aircraft with associated personnel and equipment to the safe point. The following operations are performed.

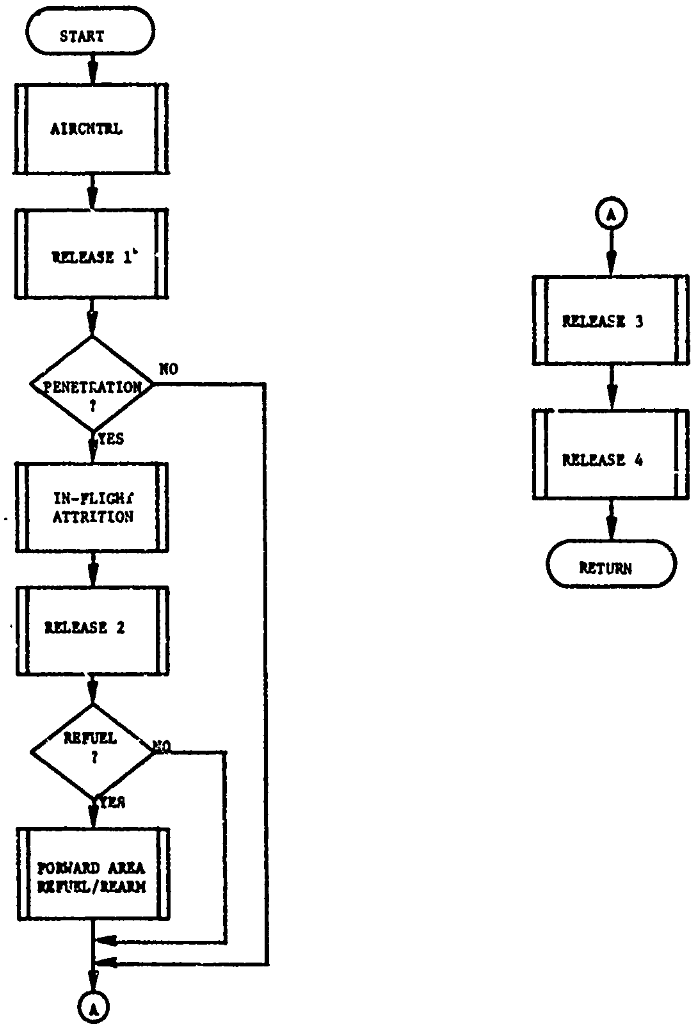

Figure 10-4. Macroflow of Release Transport - Segment 3

1. The flight speeds of the transport and escort aircraft types are obtained from the Air Ground Engagement Model data file. The speeds pertaining to the current weather and light conditions are selected and saved on the File 12 event record.

2. The fuel consumption rates for both aircraft types are obtained from the Movement Model constant data file. Those rates are also saved on the File 12 event record.

3. Subroutine PENTRATE is called to determine if the return flight will require penetration of enemy air space. A penetration flight is defined, and one in which the aircraft are being released from a unit across the penetration line is described, in Paragraph 3a(2)(b) above. If a penetration flight is to occur, this subroutine also returns the coordinates of th point along that line nearest the releasing unit. That point is called the safe point, and the returning flight path will be adjusted to fly directly to that point before returning to the base.

4. If a penetration flight is to occur, or if the transport and escort aircraft are from the same airbase, a single mission unit is created. All transport and escort aircraft with their associated crews, Class IIIA, and munitions are extracted from the releasing unit and joined into the mission unit.

5. If the two aircraft types are from different bases, and a penetration flight is not required, two mission units are created. In this case, the escort aircraft and their associated crews, fuel, and munitions are joined into one mission unit while the transport aircraft ith their associated crews and fuel are joined into the other.

6. The coordinates of the objective point of the first flight leg are set for each mission unit. If it is a penetration flight, these are the coordinates of the safe point; otherwise, they are the coordinates of the escort and transport aircraft parent bases.

7. Penetration flights are then passed to the in-flight attrition segment which controls the movement of the flight from the releasing unit to the safe point. Upon arriving at the safe point, the mission unit will be passed back to Subroutine RELEASE2. The following steps are not performed for penetration flights.

8. The distance from the releasing unit to the objective is calculated and the time of flight is determined using the flight speeds of the aircraft.

9. The events corresponding to arrival at the bases is scheduled on the File 12 automatic event table. That event will be processed by Subroutine RELEASE3 at the appropriate time.

(c) Subroutine RELEASE2 is executed in response to an event scheduled by the in-flight attrition segment which indicates that a released mission unit has arrived at the safe point. This subroutine schedules the return of the mission units to the appropriate airbases. The following procedure is performed.

1. The distance from the safe point to the transport airbase is calculated and the time to fly to the base is determined using the transport aircraft flight speed saved by Subroutine RELEASE1. The amount of fuel required for the return flight is then determined using the transport aircraft fuel consumption rate saved by Subroutine RELEASE1.

2. If the aircraft are to be returned to different bases, a mission unit is created. The transport aircraft with their associated crews and fuel are joined into that mission unit.

3. If the original mission unit did not have enough for the transport aircraft to return to their base, the unit is passed to the forward area refuel and rearm segment for refueling, after which it will return to the control of Subroutine RELEASE3.

4. The remaining equipment in the original mission unit is associated with the escort aircraft. If there is not enough fuel left for the escorts to return to their base, that unit is then passed to the forward area refuel and rearm segment, after which it will be returned to the control of Subroutine RELEASE3.

5. The mission units not requiring refueling are returned directly to their bases. Events are scheduled on the File 12 automatic event table for the arrival of the aircraft back at their bases. Those events will be processed by Subroutine RELEASE3.

(d) Subroutine RELEASE3 is executed in response to events scheduled by Subroutines RELEASE1 and RELEASE2. It updates the mission units for the flight to the base and schedules the restoration of the aircraft for reassignment. The following operations are performed.

1. The fuel, personnel, and munition present in the arriving mission unit are transferred directly to the unit status record of the airbase after subtracting fuel consumed on the return flight.

2. The landing times for the transport and escort aircraft types are obtained from the Air Ground Engagement Model data file.

3. The number of aircraft receiving B-kills is determined from the mission unit's status file. The time required to return an aircraft with a B-kill to service is obtained from the Air Ground Engagement Model data file. The landing time is added to that time, and an event to return B-killed aircraft to service is scheduled on the File 12 automatic event table.

4. The preceding step is repeated for aircraft with C- and D-kills. (A, B, C, and D kills are defined in Chapter 6 and in the description of the in-flight attrition segment contained below).

5. An event to return undamaged aircraft to service after the landing time plus the aircraft availability time is scheduled on the File 12 automatic event table. The availability time is obtained from the Air Ground Engagement Model data file.

6. Mission units are dissolved, and their identities may be used for other missions.

(e) Subroutine RELEASE4 is executed in response to an event scheduled by Subroutine RELEASE3. This subroutine is called at the appropriate time to restore aircraft into service after completion of a mission and to record landing and availability times. It increments the quantity of aircraft on hand contained on the airbase unit status record.

d. Refuel and Rearm (Segment 4):

(1) Purpose. The Forward Area Refuel and Rearm (FARR) submodel is designed to simulate the refueling and rearming of US Army aircraft performing airmobile assault operations. The model is designed to simulate the operations of mobile FARR areas during mid-intensity conflicts where there would exist a continuing and frequent requirement for rapid displacement of the FARR area. This mobility is required to ensure continuous aircraft refueling/rearming operations and to avoid destruction from enemy fire. The FARR submodel is based primarily on the results of a US Army Supply Agency study[1] and selected FMs.[2,3]

(2) Operation:

(a) Only the refueling and rearming operations are discussed in this paragraph. Resupply of fuel and ammunition to the FARR area is discussed in Chapter 9, CSS Model. When the FARR area is in hostile territory, it is always resupplied by unit distribution through an airlift operation.

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1. USACDC Supply Agency, Aircraft Refueling and Rearming in Forward Areas (ACN 17073), September 1971.

2. FM 1-15, Aviation Battalion, Group, and Brigade; FM 6-102, Field Artillery Battalion, Aerial Field Artillery; FM 17-37, Air Cavalry Squadron; FM 57-35, Airmobile Operations.

3. US Army Aviation School, ST 1-100-1, Reference Data for Army Aviation in The Field Army, January 1970.

(b) During airmobile operations, a flight of troop ships and their escorts may be required to make several trips between the pickup zone and the landing zone. A flight, arriving at the pickup zone, is sent to refuel if either of two conditions occur. The first condition is that the escort aircraft (if there are any) have expended 50 percent of any type of ammunition. The second condition is that the aircraft do not have enough fuel to make one more round trip to the landing zone with 30 minutes reserve. All aircraft sent to the FARR area are refueled and, if appropriate, rearmed.

(c) Once a determination has been made to send the flight to a FARR area, a FARR area is chosen. If the flight has a FARR area in direct support, it is sent there. Otherwise, it is sent to the nearest general support FARR area. If no general support areas are available, the flight is sent to the nearest FARR area which is in direct support of another unit. In the case where the selected FARR area is moving, under attack, or does not have sufficient fuel, an alternative FARR area is chosen.

(d) Figure 10-5 shows a schematic of the refueling and rearming process which is simulated. As shown, refueling and rearming tasks are accomplished separately, and both a refuel queue and a rearm queue are simulated. If no rearming is required, the flight leaves the FARR area as soon as all aircraft in the flight have been refueled.

(e) Once the flight arrives at the FARR area, it is put into a refuel queue. No flights are given priority service. A "first in, first served" rule is observed at both the refueling and rearming areas to facilitate the queuing process. A particular flight does not land at the FARR area until service capabilities are available. If they are not available, the aircraft are diverted to a holding area to await their turn in the refueling queue.

(f) All aircraft arriving at the FARR area are refueled. Since the Airmobile Model does not simulate fire by transport aircraft, only escort aircraft are considered for rearming. Individual aircraft are refueled and then, if necessary, rearmed, in that sequence. Within a flight, aircraft which require rearming are refueled before aircraft which do not. All aircraft are assumed to accept fuel at 50 gallons per minute at each fuel inlet.

(g) Total refuel service time for a set of aircraft, RFTPS, at a refuel area is calculated using Equation 10-4:

$$RFTPS = RFT + RFMT \qquad (10\text{-}4)$$

where:

RFT = refuel time per aircraft set (minutes)

RFMT = refuel maneuver time (minutes)

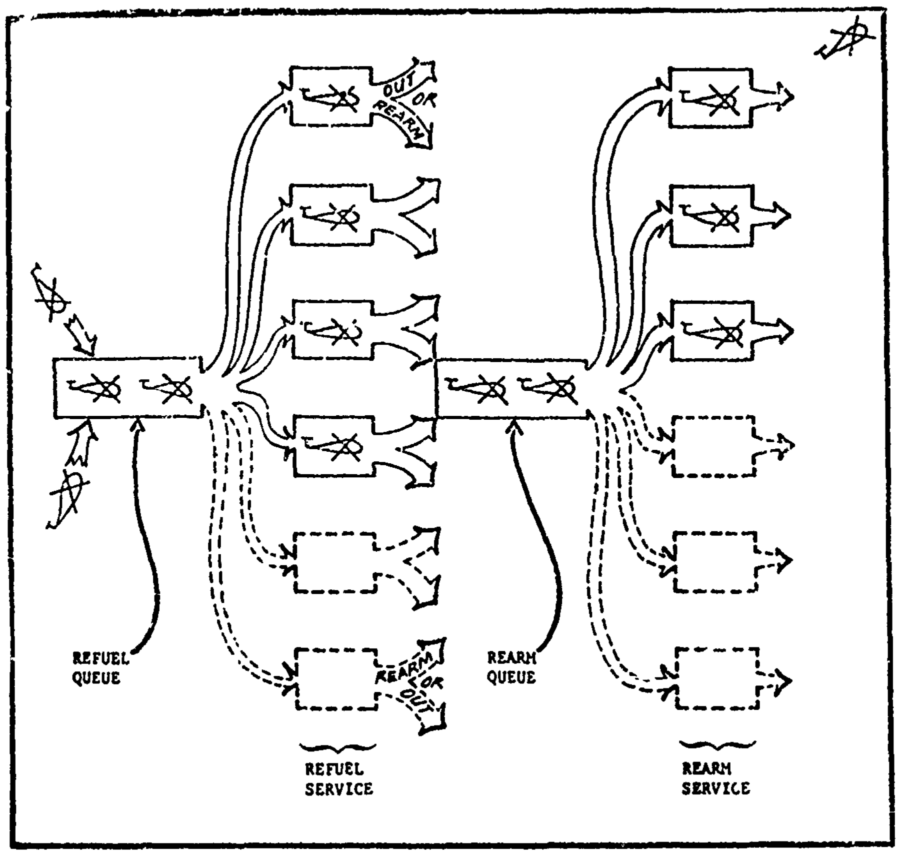

Figure 10-5. Schematic Concept of Forward Area Refueling and Rearming System

(h) The refuel time per aircraft set is found by first determining the average amount of fuel required per aircraft inlet. The average fuel amount is then divided by the intake rate of an aircraft fuel inlet. This calculation is expressed by Equation 10-5:

$$RFT\ (min) = \frac{TRF\ (gal)}{NI*RATE\ (gal/min)} \qquad (10\text{-}5)$$

where:

TFR = total fuel required by all aircraft in a flight (gallons)

NI = total number of aircraft fuel inlets

RATE = assumed rate at which aircraft can accept fuel at an inlet (currently 50 gallons/minutes).

The number of inlets is used rather than the number of aircraft in order to simulate a FARR area with different type refuel devices, each with a different number of nozzles refueling different type aircraft with varying numbers of fuel inlets. A refuel point is defined as containing one nozzle, allowing the number of fuel inlets in the flight to be matched with the refuel points.

(i) A refueling maneuver time is input to account for delays other than the actual refuel time. This includes the time required to maneuver a single aircraft into position for refueling from a position approximately 200 yards from the refuel point, time to insert nozzle(s) and commence (but not conduct) fueling, time to remove nozzles and to maneuver the aircraft clear of the refuel point.

(j) As soon as aircraft are refueled, those which require rearming are maneuvered to a rearm area where they are put in a rearm queue. Aircraft not requiring rearming are put in a holding area.

(k) All aircraft which require any ammunition are rearmed. Rearm time per aircraft set is a function of aircraft and munition type but is considered to be independent of munitions consumed. Rearm time per set of aircraft is input as constant data. The number of rearm points at each FARR area is also constant data and is input as a function of unit type designation (UTD). The number of points will be degraded if the FARR sustains loss of personnel.

(l) A second maneuver time is input to account for the delay created in rearming. This time includes the time for an aircraft to move from the rearm queue area to a rearm point plus the time required for preparing for takeoff. Total service time for a set of aircraft at a rearm area

is rearm maneuver time plus rearm time per set of aircraft. Although all aircraft in a flight remain at the FARR area until the whole flight has been processed, the aircraft leave the service point immediately on completion of servicing.

(m) Each type FARR area must be defined as a basic unit with a unique unit type designation (UTD). The number and type of FARR areas which are to be played are defined by the task organization. The amount and type equipment at each FARR area is described in TOE Load. An example of what would be at a typical FARR area located in friendly territory is shown below:

- 6 Refueling systems
- 20 500 gallon tanks
- 1 Fuel truck
- 1 Ammunition truck
- 4 Rearm points

(n) Since each refueling system has two nozzles, the FARR area has 12 outlets for fuel. Lethal areas are input for the 500 gallon tanks and for the trucks. The amount of fuel in each should be listed as secondary equipment for that item so that fuel may be attrited when the fuel tanks and trucks are hit by artillery fire. Lethal areas of aircraft are also input so that they can be attrited by artillery fire while in the refuel and rearm areas. In determining the number of FARR areas required, the tradeoff between system utilization and waiting time must be considered. A FARR area should have enough service points, personnel, and equipment so that a long waiting line does not develop. On the other hand, the more refueling and rearming points at a forward area, the greater the system's idle time will become. Furthermore, the greater the number of service points, the larger the area to support the refueling/rearming activities must be, causing problems in clearing and securing.

(o) In order to more clearly explain how the model simulates the rearming and refueling activities at a FARR area, an illustrative example is developed below. The situation is shown in Figure 10-6.

Flight	Aircraft in Flight	Number Aircraft To Be Rearmed	Refuel Service Time Per Acft Set (min)	Rearm Service Time Per Acft Set (min)	Number Refuel Points	Number Rearm Points
1	13	3	2	20		
2	4	4	3	15	10	5
3	2	0	4	0		
4	17	4	2	14		

Figure 10-6. Illustrative Example of Refuel/Rearm Situation

Four flights simultaneously arrive at a FARR area at time t equal zero. The FARR area has 10 refuel points and five rearm points available. There is a different number of aircraft in each flight. Note that the refuel and rearm service times per aircraft may be different for different flights. These times depend on the type aircraft and their munition loads. In flight 1, only three of a total of 15 aircraft require rearming. The assumption is that this flight consists of three escort aircraft and 12 transport aircraft. The number of escort aircraft in the other three flights are 4, 0, and 4, respectively. Figure 10-7 shows the sequence and times at which the four flights would be refueled and rearmed as simulated in the FARR model.

(p) Since the rearming of flight 4 could not begin until time t = 22 minutes, the flight does not land at the FARR area until time t = 20 minutes, at which time it immediately starts refueling. This 2-minute time difference allows the first ten aircraft of flight 4 to complete refueling at the time rearm points in the rearm queue become available. In order to minimize the number of aircraft on the ground at the FARR area at any one time, a flight does not land at the FARR area until it can start refueling. Thus, the aircraft are vulnerable to artillery fire for a shorter time period.

(q) Since three of the 15 aircraft of flight 1 require rearming, flight 1 departs the FARR area at t = 22 minutes. Flight 3 does not require any rearming; hence, it is refueled as soon as any refueling capability becomes available (t = 4 minutes) and departs immediately after refueling (t = 8 minutes). Note that flight 4 does not leave the FARR area until t = 49 minutes, even though refueling of all aircraft was completed at t = 24 minutes, and only four aircraft in the flight required rearming.

(r) As is illustrated in Figure 10-7, each flight arrives at and departs from the FARR area as a complete flight, although some aircraft may be refueling while others are rearming. Only those aircraft which require rearming are sent to the rearm queue. Thus, if no aircraft in a flight require rearming, the entire flight departs the area as soon as refueling is completed.

e. In-flight Attrition:

(1) General:

(a) Purpose. The In-flight Attrition Submodel is designed to simulate the ground-to-air attrition incurred by any aircraft which flies through hostile airspace. This submodel is intended to represent the principal determinants of attrition in sufficient detail to permit realistic simulation of airmobile and other air operations within the DIVWAG system. Rather than depend upon the results of any external high-resolution models, this submodel is designed to use, as input, available basic data on air defense weapons and aircraft.

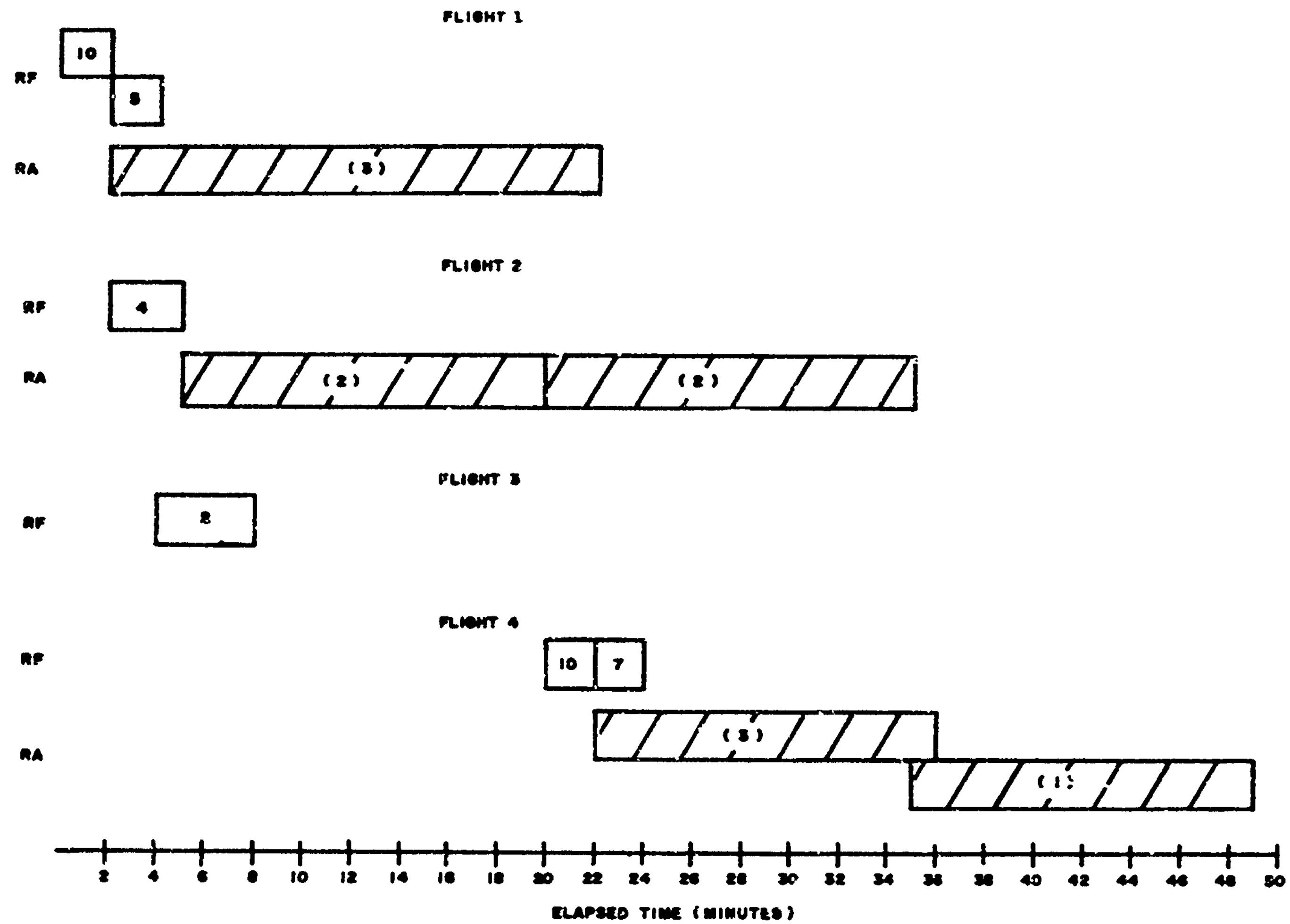

Figure 10-7. Example of Refuel and Rearm Scheduling

(b) Capabilities. The In-flight Attrition Submodel can accommodate for each force (Red and Blue), nine types[4] of aircraft and 15 types of ground-based air defense weapons, including both guns and missiles. Any resolution unit which currently contains any of the specified types of air defense weapons, is considered by this submodel to be an air defense capable unit (ADCU). The submodel considers the air defense capability, size, and location of each such ADCU versus the position and speed of the air unit on its current flight leg. Attrition by ground-based air defense weapons is restricted to aircraft and their contents. Provision exists for addition of an air to-ground attrition routine at a later date. Suppression of air defense weapons is simulated in terms of input air defense suppression duration times applied for each attack by escort aircraft, TACAIR, or ground-based artillery. This submodel dispatches a pair of escorts, if available, to attack any firing ADCU which is within a limited distance from the air unit. The submodel requests quick-reaction fire support by TACAIR or ground-based artillery against any firing ADCU which is beyond a specified distance from the flight path. Aircraft attrition calculations for guns employ aircraft presented area, weapon accuracy, and aircraft vulnerable areas to each air defense weapon type, based on the average engagement geometry of relatively short segments of the flight path. For missiles, accuracy and probability of kill versus miss distance are used. Only unsuppressed ADCUs are permitted to fire. Terrain masking; weapon limitations of range, altitude, slew rate, and/or launch envelope; and delays for acquisition, reaction, and projectile flight are considered in determining whether projectiles can intercept the flight on a particular segment. The number of projectiles which can intercept on the segment is further determined by number of unsuppressed weapons currently on hand, ammunition on hand, and rate-of-fire characteristics of each weapon type. Degradation for weather and visibility conditions, electronic countermeasures (ECM), weapon system reliability, and evasive flight is included. Aircraft losses are recorded in four kill categories; quick kills (Category A), forced landings (Category B), mission aborts (Category C), and other damage (Category D). Cargo and troop losses are proportioned to total aircraft kills.

(c) Approach. The In-flight Attrition Submodel utilizes extensively the DIVWAG event sequencing system. The basic approach used is to consider the future flight path a leg at a time; to start with a limited number of essential criteria; and to use them to identify and isolate, a short distance in advance of the actual air unit, portions of the flight leg where air defense engagement will be possible. Progressively detailed analysis is then applied to narrow the scope of consideration and refine the level of information about anticipated interactions until segments of the flight leg are defined on which unique sets of air defense weapons will intercept the air unit. When the air unit has reached the end of each such segment, final filtering makes use of up-to-date information, and a set of attrition calculations is employed to assess fractional aircraft losses over the entire segment.

4. Two types in any one flight.

(2) Submodel Operation. The submodel is composed of three basic sections. Section 1 identifies segments of the flight leg where aircraft attrition is possible. Section 2 breaks these flight leg segments into subsegments, termed constant fire subsegments (CFS) within which the air unit is expected to be subject to attrition by a unique and constant set of air defense weapons. Section 3 calculates and assesses to the air unit all losses incurred on a CFS.

(a) Callers. Each of three different DIVWAG models may call the In-flight Attrition Submodel in order to initiate assessment of aircraft losses on a specific flight leg of an overall flight path. These models, termed primary callers, include the Airmobile Model, the Reconnaissance Submodel of the Intelligence and Control Model, and the Air Ground Engagement Model. Also, the DIVWAG event scheduling system may call the In-flight Attrition Submodel as a result of events set during the course of assessment of aircraft losses on a specific flight leg. The latter type of call is termed a secondary call. All primary and some secondary calls go to Section 1. Primary calls carry identification of caller, a specification of the flight leg to be assessed, whether it is the first or subsequent leg of flight, and the identify of the air unit which may incur losses. Secondary calls carry this information plus a key to an additional storage file which can contain details of the assessment in process.

(b) Section 1. This section identifies segments of a flight leg where attrition may occur. In keeping with the event sequencing design of DIVWAG, such segments are identified prior to the time at which the air unit is to actually traverse the flight leg. A logical flow diagram of Section 1 is found at Figure 10-8.

1. A determination is made as to whether the location of the air unit is updated to the end of the flight leg. A second check determines whether the air unit has actually reached the end of the current flight leg. If so, control is returned to the primary caller, so that the next flight leg (if any) on the flight path may be presented for assessment. If the air unit has not reached the end of its current flight leg, the current position of the air unit is taken as the initial point of reference from which to conduct a search for ADCUs which may have an effect upon the air unit.

2. In order to identify those segments of the flight leg where aircraft attrition is possible, all ADCUs of the opposing force are examined against two basic criteria, from a point which progresses in short steps (500 meter increments) from the beginning to the end of the flight leg, in advance of the actual air unit. One criterion is whether line of sight exists from the center of the ADCU to the point. The other criterion is whether the point is within maximum effective weapon range of at least

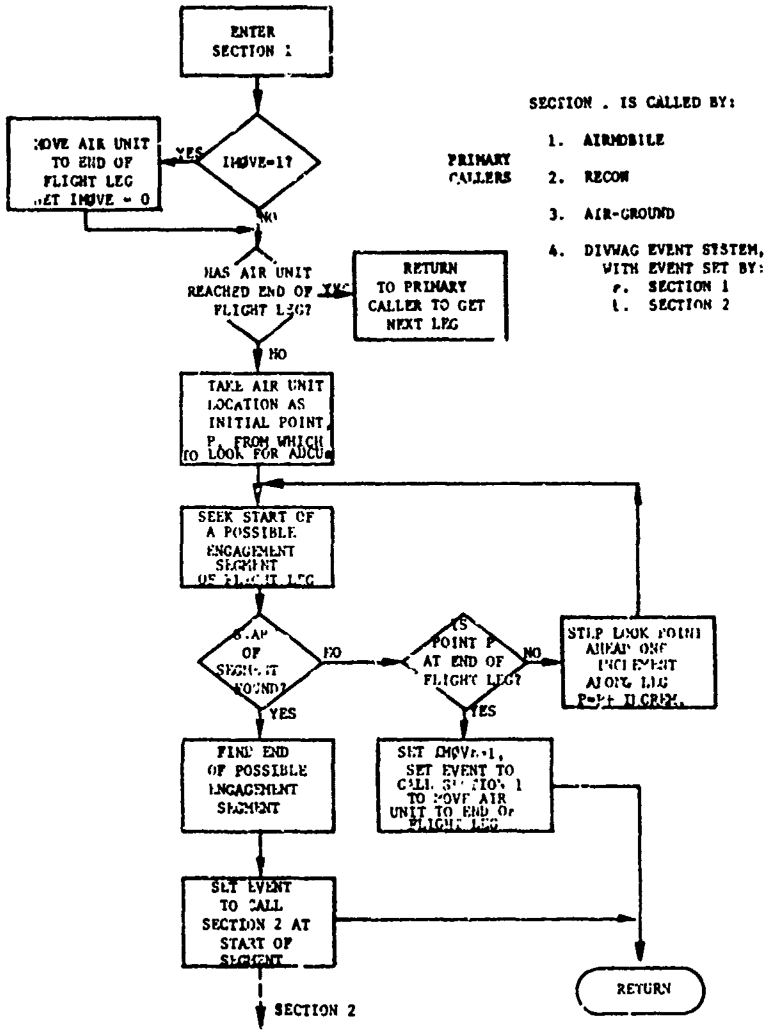

Figure 10-8. Macroflow of In-Flight Attrition Submodel (Section 1)

some[5] of the longest range weapons in the ADCU. If both criteria are met for any ADCU from a given point, that point is then considered to be within a flight leg segment over which the air unit is subject to possible attrition. If two adjacent points meet both criteria, the step interval between points is presumed also to be within a flight leg segment on which attrition is possible. The first point which fails to meet both criteria marks the end of the possible attrition segment, while conversely the first point which meets both criteria marks the beginning.

3. If the point reaches the end of the flight leg with no possible engagement segments being found, the coordinates of the air unit are updated to the end of the flight leg and an event is set for the time at which the air unit, at its assigned flight speed, should reach the end of the flight leg. This event calls Section 1. After this move event is executed, control returns to Section 1, so that the primary caller may be notified and any subsequent flight legs may be presented for assessment.

4. Section 1 also keeps track of which ADCUs are involved in meeting both of the above criteria as a basis for determining the end of a segment. Whenever an ADCU is added or dropped from the roster of those that meet both criteria, a segment is considered to end. Whenever the end of such a segment is found by this section of the submodel, an event is set to enter the second section of the submodel at the time the flight is anticipated to arrive at the start of this segment, so that more detailed geometric, timing, and related analysis can be performed.

(c) Section 2. Section 2 is called in response to the events set in Section 1 just described. Associated with each such event are data specifying the flight leg and the air unit, and also details from Section 1 describing the segment of the flight leg on which engagement was anticipated to be possible including the identity of the ADCU(s) expected to engage. A logical flow diagram of Section 2 is shown at Figure 10-9.

1. The first step in Section 2 is to update the position of the air unit to the location of the start of this segment of the flight leg.

2. To perform its primary task, Section 2 must examine the current status and air defense capability of each air defense weapon system in each ADCU expected by Section 1 to be able to participate on this segment of the flight leg. This detailed examination by weapon type reveals which, if any, weapons are expected to be capable of delivering projectiles which will intercept the air unit on this segment of the flight leg. Since the ADCU has line of sight on this segment, all contained weapons are temporarily

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5. For purposes of the In-flight Attrition Submodel, all air defense weapons in a given ADCU are assumed to be evenly distributed on the circumference of a circle whose center is that of the ADCU and whose radius is one-half of the width or depth of the ADCU, whichever is smaller.

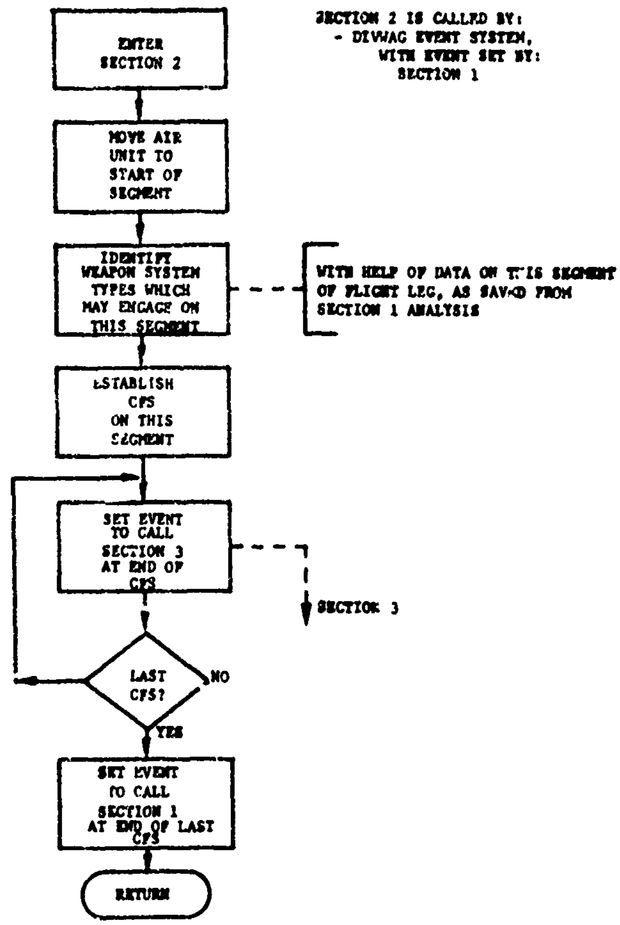

Figure 10-9. Macroflow of In-Flight Attrition Submodel (Section 2)

assumed, for this examination, also to have line of sight. The range of each weapon type, however, is critical in this examination. Other factors such as ammunition supply and specific weapon capability limits are also considered here. This examiniation also determines when the projectiles fired by each capable weapon are expected to begin intercept and cease intercept of the air unit. This determination of timing requires consideration of the immediately preceding activity of the pertinent weapons, or the time when the air unit will enter range of a given weapon type, as well as any delay times which may be appropriate to the specific circumstances. Delay times which may be appropriate include acquisition delay, reaction time, and projectile time of flight. For example, if the prior activity of a weapon were, for a sufficient period, firing at this air unit, then no delay would apply to intercept by its projectiles on this segment of the flight leg. If, however, a weapon had not yet acquired the flight, then acquisition delay, reaction time, and projectile time of flight would all be applicable. In the latter case, it might be determined that the weapon could not intercept on this segment of the flight leg. In this manner, Section 2 analyzes the capability and timing of all the air defense weapons in the pertinent ADCU(s) and then sorts out the results by weapon type according to anticipated start and end of projectile intercept with the air unit on this segment of the flight leg. These sorted results reveal the flight subsegments within each of which the air unit is expected to be subject to attrition by a unique and constant set of air defense weapons. These flight subsegments will henceforth be referred to as Constant Fire Subsegments (CFS).

3. For each CFS established, Section 2 sets an event to call Section 3 at the end time of the CFS, for the final attrition calculations. Finally, Section 2 sets an event to call Section 1 at the end of the last CFS defined. If no CFS was defined, this event is set for the end of this segment of the flight leg.

(d) Section 3. Section 3 is called in response to the attrition event scheduled in Section 2. Based on the data on the CFS generated in Section 2, adjustments for status changes are made and weapons capabilities are now elaborated upon to approximate average capability over the CFS, suppressive fire and effects on AD weapons are accounted for, and the aircraft attrition is calculated. A logical flow diagram of Section 3 is shown at Figure 10-10.

1. To prepare for attrition calculations, Section 3 references the current status of the various air defense weapon types which were anticipated (by Section 2) to be participants in the attrition inflicted on the flight during this CFS. Current time (and therefore status) is for the end of the CFS. The attrition calculations must exclude weapons which are destroyed and weapons which are suppressed. The current number of weapons

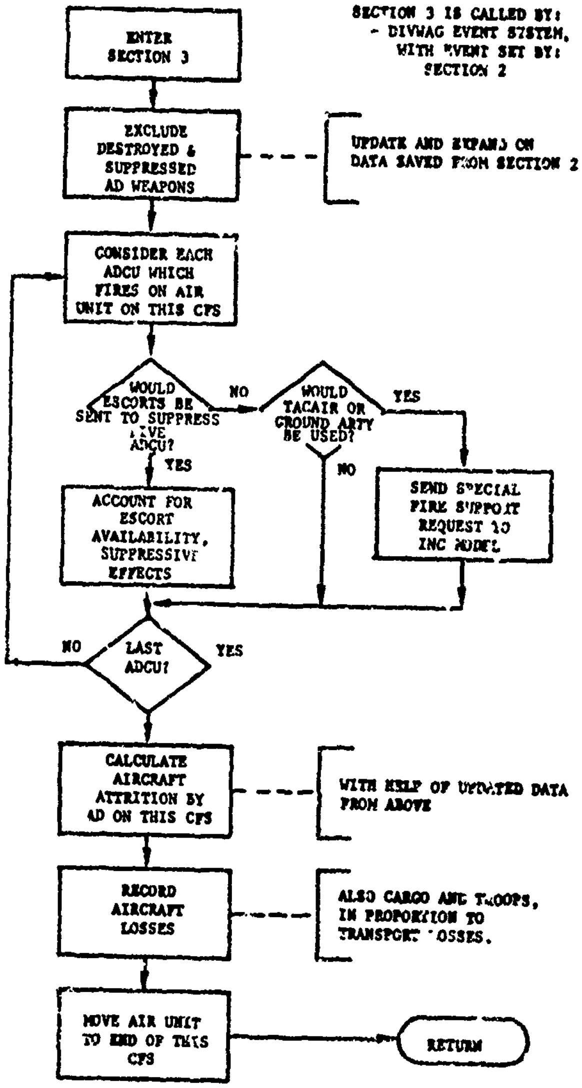

Figure 10-10. Macroflow of In-Flight Attrition Submodel (Section 3)

on hand is accepted[6] as adequately reflecting weapons destroyed.

2. Because of the potential impact of suppression on results, a look back is made to CFS start time to evaluate suppressive effects from all sources at all points during the CFS. Air defense suppressive effects are represented by air defense suppression time durations, given in input, applied by Section 3 to the last time at which an ADCU was attacked. The entire ADCU is assumed to be affected uniformly. If a suppression time duration for a given ADCU is not found to overlap any part of the CFS, the ADCU is considered to be firing at CFS start time. In this case, a decision is made by Section 3 as to whether a pair of escorts, if available, would have been dispatched to suppress the ADCU. If the decision is positive, the suppressive effect of the escort action is superimposed, and the overlap of suppression duration with CFS is recalculated. In any case, the fraction of the CFS which is overlapped by the foregoing suppression evaluations, for a given ADCU, is used in the attrition calculation to degrade the amount of fire that any weapons in that ADCU can place on the air unit during this CFS. If escorts are unavailable to attack a firing ADCU, or if the firing ADCU is beyond the limits of attack escorts (to the sides of the flight path), a request for quick-reaction TACAIR or ground-based artillery fire support is made to the Intelligence and Control Model. The suppressive effect of any such external fire support rendered, however, is considered only on subsequent CFS.

3. Preparatory to attrition calculations, Section 3 establishes the X, Y, and Z coordinates of the midpoint of the CFS. The midpoint is later used to calculate the aspect angle of the air unit and its slant range from the center of each ADCU participating.

4. If more than one ADCU was determined by Section 2 to be a participant on the CFS currently being processed for attrition, the ADCUs are considered separately; and within an ADCU, those weapon types determined to be participants are also considered individually. For each such weapon type, a series of calculation steps is performed, employing slant range and related geometry of the midpoint of the CFS and reflecting the current number of weapons and their capability after adjustment for air defense suppressive effects, weather-visibility, and other current conditions. Different calculation procedures are used for missiles, as distinguished from guns. The result of these calculations is a set of probabilities of kill, by weapon type, by aircraft type in the unit, and by each of four kill-type categories. Each missile is assumed to be targeted against a single aircraft, of the largest type in the air unit; therefore, resultant missile probabilities of kill are

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6. Ideally, an adjustment should be made to reflect average number on hand over the length of the CFS. Provision is made to add such an adjustment later. As long as the segment is relatively short, however, little distortion should result.

considered equivalent to fractional losses. Rounds fired from guns are assumed to be equally distributed over all aircraft in the flight at the start of the CFS. Gun probabilities of kill are, therefore, per aircraft.

5. Probabilities of kill for all gun weapon types in all ADCUs participating are then combined by forming the product of the respective probabilities of survival, for each kill type and aircraft type. The aggregate probability of kill for all gun weapons, by kill type and aircraft type, is then one minus the respective compound probability of survival ($1-P_S$). Missile losses are subtracted first, from aircraft in the air unit. The aggregate gun probability of kill is multiplied by the remaining aircraft of respective type to generate aggregate losses to guns.

6. Finally, losses to aircraft are recorded, and the position of the air unit is updated to that of the end of this CFS.

(3) Section 1 Operating Details:

(a) General. This subparagraph is a supplement to the preceding discussion of Section 1 of the In-flight Attrition Submodel. The general structure, concept, and macroflow of Section 1 was described above. This subparagraph, in contrast, describes how Section 1 performs its principal functions. Description focuses on the key algorithms and logical processes of Section 1.

(b) Incoming Data. Four essential data items are included in the data which accompany a call to Section 1. The first of these items is an operation code which causes the call to be routed to Section 1. The second item is the identity (IUID) of the air unit. The third item is a flight continuity code (JPASS) which denotes whether this is the initial or a subsequent pass through the In-flight Attrition Submodel on this flight path. The fourth item is a code which can be used to return to the primary caller when necessary. Section 1 then obtains additional data as needed. The first such items obtained include the beginning and ending X and Y coordinates of the current flight leg, obtained from the Unit Status File of the air unit.

(c) Flight Leg:

1. Establishment of Z Coordinates. Since the flight leg is defined so far only in the X, Y plane, the beginning and ending Z coordinates must be established by Section 1. The elevation of the ground at the beginning and ending X, Y coordinates is obtained and the height of the flight above terrain, obtained from the flight altitude variable on the Unit Status File of the air unit, is added to yield the Z coordinates of the beginning and end of the flight leg, in meters.

2. Orientation of the Flight Leg. The orientation of the flight is established in angular terms, so that coordinates of various points along the flight leg can be readily established. Orientation in the X, Y plane is represented by angle B, in radians. Angle B is calculated by the expression:

$$B = \tan^{-1} (y/x) \tag{10-6}$$

where:

x = difference between beginning and ending X-coordinates

y = difference between beginning and ending Y-coordinates

Orientation of the flight leg in the vertical plane is represented by angle R, which is calculated by the expression:

$$R = \tan^{-1} (Z_2 - Z_1)/d) \tag{10-7}$$

where:

Z_2 = ending Z coordinate

Z_1 = begining Z coordinate

$$d = \sqrt{x^2 + y^2} \tag{10-8}$$

The flight leg is assumed to be a straight line for purposes of establishing position of the air unit. Certain trigonometric functions of these angles are calculated at this time for later use in updating positions.

3. Air Unit Initial Position. The position of the air unit, at the time of primary call to Section 1, is at the beginning of the flight leg. At the time of secondary call, air unit position may have been updated appropriately to some point along the flight leg.

(d) End-of-Flight-Leg Check for Air Unit. In case the air unit position has been updated, through steps taken in other parts of the in-flight attrition process, to the end of the current flight leg, a check is made. If the unit is at the end of the flight leg, control is returned to the primary caller to permit presentation of the next flight leg, if any.

(e) Initial Position of Reference Point P. On the first pass through Section 1, signified by the zero value of the pass code (third item of incoming data), the position of the reference point, P, is set to the location of the air unit, which is at the beginning of the flight leg. On all subsequent passes through Section 1, signified by the value 1 of the pass code, point P is set to the position it held at the end of the last pass, as obtained from the stored X and Y coordinates. The Z coordinate is obtained by use of the utility routine, ELEVATE.

(f) Search for Enemy Units. From the look point, the utility routine, SEARCH, is used to generate a list (list 1) of all enemy units within a specified radius. The radius is limited, to reduce unnecessary computation, depending on the altitude of the flight above the terrain and foliage. If altitude is within 100 feet, the look radius is set to 4000 meters. If altitude is between 100 and 1000 feet, the radius is set to 6000 meters. If altitude is between 1000 and 3000 feet, radius is 10,000 meters, while for over 3000 feet, radius is 20,000 meters.

(g) Developing List of AD Weapon Types Ranked in Order of Decreasing Range. In order to screen the list of enemy units, just obtained, for ADCUs in range, a list of all AD weapon types ranked in decreasing order of maximum effective weapon range is formed. The weapon types specified to have AD capability are obtained, together with their maximum effective ranges, from the input data file.

(h) Screening for ADCUs in Range. The list of enemy units within search radius is screened next for ADCUs whose longest range AD weapon can reach the reference point, P. Each enemy unit is examined to see if it contains any weapons of any AD type, starting with the longest range type, according to the ranked list of types. If any AD weapons are found, the distance, d, between point P and the ADCU is calculated by the expression:

$$d = \sqrt{(X_p - X_u)^2 + (Y_p - Y_u)^2} - 1/2 \text{ the minimum of } D \text{ or } W \qquad (10\text{-}9)$$

where:

X_p = X coordinate of point P

Y_p = Y coordinate of point P

X_u = X coordinate of ADCU center

Y_u = Y coordinate of ADCU center

D = depth of ADCU, in meters

W = width of ADCU, in meters

The distance, d, is then compared with the maximum effective range of the weapon type to determine if the ADCU is within range.

(i) Screening for Line of Sight. If the ADCU is within range, it is also tested for line of sight. The line of sight function, LOS, is used. The operation of this function is described in Chapter 2. Function LOS is given the X, Y, and Z coordinates of the imaginary reference point, P, plus a flag indicating where to find the X, Y, and Z coordinates of the ADCU. A yes or no answer is returned for existence of line of sight between these two points. While this screening proceeds, the earliest time that line of sight is gained by any ADCU in range is recorded for use in Section 2.

(j) Incrementing Location of Reference Point P. If no ADCU is found within range of, and with line of sight to, the air unit at the start of the flight leg, the reference point, P, is stepped ahead along the flight path by an incremental distance, and the search and screening process is repeated. The incremental distance is a fixed value which is a product of a variable time increment and the flight speed of the air unit. The time increment t_i, is calculated by the reverse process:

$$t_i = d_i/s \tag{10-10}$$

where:

d_i = incremental distance

s = flight speed of the air unit

The incremental distance is hard-wired and is chosen to compromise adequately between need for accuracy of results and need to minimize computer running time. The value currently used is 500 meters. The new coordinates of point P are calculated, using trigonometric functions of the angular orientation of the flight leg, as described above. The new coordinates are:

$$X = X_o + D \cdot \cos B \tag{10-11}$$

$$Y = Y_o + D \cdot \sin B \tag{10-12}$$

$$Z = Z_o + D \cdot \sin R \tag{10-13}$$

where:

X_o = initial or previous X coordinate of point P

Y_o = initial or previous Y coordinate of point P

Z_o = initial or previous Z coordinate of point P

D = the cumulative distance of all incrementation to date on this flight leg

B and R are angles defined in Paragraph 3e(3)(c)2, above.

The cumulative distance, D, of all incrementation to date on this flight leg is obtained by the expression:

$$D = s \cdot t \tag{10-14}$$

where:

s = flight speed of the air unit

t = the cumulation of all time increments so far on this flight leg.

If the incrementation should push the new coordinates beyond the end of the flight leg, this condition is detected, and the coordinates are reset to those of flight leg end.

(k) End-of-Flight-Leg-Check for Reference Point P. The check to determine whether point P has reached the end of the flight leg is made on each pass through the point P incrementation loop.

(l) Flying Air Unit to End of Flight Leg. If point P was found to have reached the end of the flight leg, no further preparatory processing of this flight leg will occur. Accordingly, the location of the air unit is updated to the end of the flight leg. This is done by resetting air unit coordinates to coordinates of flight leg end. An event is then set to call Section 1 at the time the air unit, flying at its given speed, will reach the end of the flight leg. The time of the event, t, is found by the expression:

$$t = t_o + d_r/s \tag{10-15}$$

where:

t_o = current time

d_r = distance between air unit current location and end of flight leg

s = flight speed

The distance, d_r, is calculated by the equation:

$$d_r = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad (10\text{-}16)$$

where:

X_1 = current X coordinate of air unit

Y_1 = current Y coordinate of air unit

X_2 = flight leg end X coordinate

Y_2 = flight leg end Y coordinate

When Section 1 is called at this event time, it senses that the air unit is at the end of the flight leg and therefore returns to the primary caller so that any following flight leg may be presented for in-flight attrition.

(m) Establishment of Possible Engagement Segments:

1. Finding First Start. If, for the first time on this flight leg, after the screening steps described above, one or more ADCUs remain with range and line of sight to the reference point, P, then the start of the first possible engagement segment on this flight leg has been found. The coordinates of the start of this possible engagement segment are equated to those of point P. The identity of each ADCU which could possibly engage at this point is placed on a list (list A) which will assist in finding the end of the first engagement segment.

2. Finding First End. The end of the first possible engagement segment on this flight leg is sought as soon as the start has been found. To find the end, the location of reference point P is stepped ahead one increment. From the new point P, a new search for enemy units is conducted, and all units found are screened for AD weapon range and line of sight. The identity of each ADCU which passes the screening is placed on a list (list B). The contents of list B is now compared with the contents of list A. If the same ADCUs are on both lists, the location of point P is again incremented, and the search and screening steps are repeated to generate a new list B. As soon as the contents of lists A and B disagree, then the end of the first possible engagement segment has been found. The end coordinates of this segment are equated to those of point P.

3. Finding Subsequent Start and End. The start and end of subsequent possible engagement segments of the flight leg are found in the same manner as described in the preceding two paragraphs, while the reference point, P, continues to progress along the flight leg. The end of a previous segment will be the start of a subsequent segment only if one or more ADCUs remain able to engage. Otherwise, a portion of the flight path will intervene on which no engagement is possible.

(n) Setting Event to Call Section 2. Whenever the end of a possible engagement segment of the flight leg is found, an event is set to call Section 2, so that more detailed analysis of engagement possibilities can be performed. The time at which Section 2 will be called is set to the time at which the air unit should arrive at the start of the possible engagement segment. This time is directly available, since it has been maintained and updated by all time increments used in moving point P since the first call to Section 1.

(o) Data Stored. Whenever an event to call Section 2 is set, data are stored for later use. The items include the total number and identity of each ADCU on list A for the particular segment of the flight leg, the beginning and ending X and Y coordinates of the segment, the start time of the segment, and the time at which line of sight is first gained (air unit mask time), if at all, on this segment.

(4) Section 2 Operating Details:

(a) Incoming Data. The same four essential items which are incoming to Section 1 also accompany a call to Section 2. These are the call routing code, the identity (IUID) of the air unit, the flight continuity code (JPASS), and the code used by Section 1 to return to the primary caller. Section 2 then obtains additional data, including the data stored by Section 1 (see Paragraph 3e(3)(o), above, AD weapon characteristics) and the unit status file of the air unit, containing the X, Y coordinates of the flight leg.

(b) Update of Air Unit Location. An initial step taken by Section 2 is to move the air unit to the X, Y coordinates of the start of the possible engagement segment. These coordinates are included in the data stored by Section 1.

(c) Length of Possible Engagement Segment. The length, L, of the possible engagement segment is calculated by the expression:

$$L = \sqrt{(X_e - X_b)^2 + (Y_e - Y_b)^2} \qquad (10\text{-}17)$$

where:

X_e = X coordinate of end

Y_e = Y coordinate of end

X_b = X coordinate of beginning

Y_b = Y coordinate of beginning

(d) Setting Flight Continuity Flag. If this is the first time that Section 2 has been called for this air unit's current flight through hostile air space, the flight continuity flag, JPASS, an essential incoming item of data, will enter with a value of 0, which was set by the primary caller. Section 2 checks on the value of JPASS, and if it is found to be 0, resets it to a value of 1. The value 1 remains for all subsequent flight legs and signifies to the various parts of the In-flight Attrition Submodel that any call with this value is a continuation of a flight already in progress, rather than the start of a new flight.

(e) Determining Initial Value of Last Event Time. The time of the end of the last Constant Fire Subsegment (CFS) defined for this air unit flight path is an important reference value throughout Section 2. If this is the first time that Section 2 is called for a given air unit flight path, no prior CFS can have been defined. In this case, Section 2 sets the last event time variable, LASTET, equal to the start time of this possible engagement segment of the flight leg, as stored in Section 1. If, however, this is not the last call to Section 2 for the given air unit flight path, last event time is found from the stored records of CFS found on a previous pass through Section 2. In case no record yet exists, the value generated on the first pass is used.

(f) Processing ADCUs Which Can Possibly Engage. Each ADCU designated by Section 1 as possibly being able to engage the air unit on this segment of the flight leg is put through a series of processing steps.

1. Finding Air Unit Crossover Point Versus this ADCU. The crossover point is the point on the line through the ends of this possible engagement segment which is nearest to the ADCU. The position of the crossover point is returned in terms of a variable which reflects the fractional position of the point between the begin and end of the segment. or, if the point is beyond an end, the fractional degree of excess, with a sign to indicate the end exceeded.

2. Screening Weapon Type Capability in This Situation. Within a given ADCU, the capabilities of each AD weapon type are first grossly screened to eliminate from further consideration weapon types which cannot engage in this particular situation. A series of screening checks is employed based on the current status of the ADCU.

a. Weapon Defense Responsibility Radius. If the air unit is outside the input-specified radius of defense responsibility of a given AD weapon type, that type is dropped from further consideration. Distance, d, between air unit and AD weapon, for this check, is obtained by the equation:

$$d = \sqrt{(X_b - X_u)^2 + (Y_b - Y_u)^2} + 1/2 \text{ the minimum of } D \text{ or } W \qquad (10\text{-}18)$$

where:

X_b = X coordinate of beginning of possible engagement subportion

Y_b = Y coordinate of beginning of possible engagement subportion

X_u = X coordinate of ADCU center

Y_u = Y coordinate of ADCU center

D = depth of ADCU, in meters

W = width of ADCU, in meters

b. AD Weapons on Hand. If any AD weapons of this type remain on hand (i.e., remain undestroyed), this type is considered further. Otherwise it is dropped.

c. Ammunition on Hand. This weapon type must have some of the proper type of ammunition on hand for the weapon type to be considered further.

d. Weather-Visibility Condition. The current weather-visibility condition is obtained by use of the utility routine WEATHR, which tells whether it is day or night and good or poor weather. Input data for the weapon type specifies whether the weapon is capable of firing effectively in either nighttime or poor weather conditions. If a condition prevails in which the weapon cannot fire effectively, it is not considered further.

e. Aircraft Altitude. Maximum and minimum aircraft altitude capability of the AD weapon type, from input data, is compared with aircraft altitude. If the aircraft altitude is within weapon capability limits, the weapon continues in consideration.

f. Aircraft Speed. Input data also contain maximum and minimum aircraft speed capability of the weapon type. If the aircraft is

within weapon capability limits, the weapon type continues to be considered.

g. IR Lock-On Boundary. Input data provide a simplified boundary representation for the capability of infrared-seeking missiles to achieve lock-on. The input is a set of boundary distances as a function of seven horizontal aspect angles of the aircraft trajectory. For comparison with the input data, the horizontal aspect angle of this air unit and its distance from the weapon is calculated. Boundary distance is interpolated linearly, between the nearest two of the seven input aspect angles. Air unit distance from the weapon is the same distance, d, as calculated for comparison with defense responsibility radius, above. Horizontal aspect angle of the air unit trajectory is calculated with the assistance of the utility routine DISTPL. This routine is given the begin and end X, Y coordinates of the possible engagement segment and the X, Y coordinates of the ADCU, and returns a perpendicular distance, b, from the ADCU to the line passing through the begin and end coordinates (see Figure 10-11). The third side, a, of the right triangle of sides a, b, d is calculated by the expression:

$$a = \sqrt{d^2 + b^2} \qquad (10\text{-}19)$$

The horizontal aspect angle is defined here as the angle A, between the sides representing the perpendicular distance, b, and the ADCU-to-begin distance, d. The tangent of this aspect angle equals a/b. This aspect angle, A, is therefore calculated by:

$$A = \tan^{-1} ({}^{a}/b) \qquad (10\text{-}20)$$

If the interpolated boundary distance exceeds distance d, the weapon continues to be considered.

h. Slew Rate. The angular rate of the aircraft with respect to the ADCU is calculated and compared with the maximum slew or tracking rate capability of the AD weapon, from input data. Weapon capability must exceed aircraft angular rate for the weapon to be considered further. Aircraft angular rate, $\dot{\theta}$, is calculated by the expression:

$$\dot{\theta} = \text{cosine } A \cdot {}^{s}/d \qquad (10\text{-}21)$$

where:

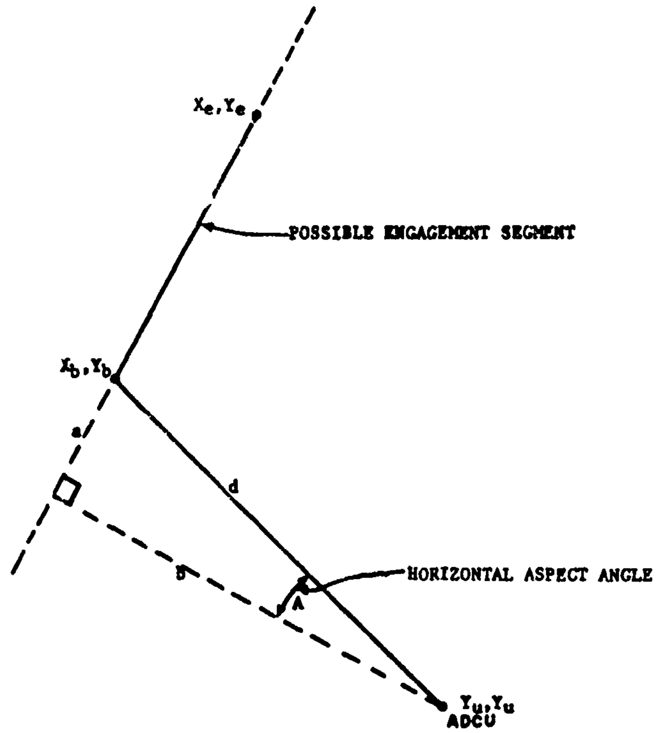

Figure 10-11. Horizontal Aspect Angle

A = horizontal aspect angle, as defined in preceding paragraph

s = speed of air unit

d = distance between ADCU and air unit as used in preceding paragraph.

3. Range of AD Weapons. For use in determining the portions of the flight path that each weapon type can reach, the position of weapons in the ADCU must be considered. The AD weapons are assumed to be uniformly distributed on the circumference of a circle whose diameter is the minimum of the depth and width of the ADCU. Thus one-half the diameter of that circle is added to the maximum effective weapon range of each weapon type when considering range intercept points on the flight path.

4. Determining Range Intercept Points on Flight Path. To determine where on the flight path the range of any weapon type, in a given ADCU, can begin to intercept and will cease intercepting, the adjusted weapon range as defined in the preceding paragraph is used. These two points of intercept are determined by using the utility routine CHORD. This routine is given the X, Y coordinates of the ADCU, the X, Y beginning and ending coordinates of the possible engagement segment, and the adjusted AD weapon range. This routine returns the X coordinates of the two points where a line extended through the possible engagement segment is intercepted by the range. The X coordinate corresponding to the start of range intercept is identified and so labeled (X1), as is the X coordinate corresponding to the end of range intercept (X2). This identification is accomplished by reference to the order of the X values of the beginning and ending of the possible engagement segment together with those of the two points. The corresponding Y coordinate for each of these two intercept limits is obtained from the line of the possible engagement segment by the expression:

$$Y_p = (Y_e - Y_b) \cdot (X_p - X_b) / (X_e - X_b) + Y_b \qquad (10\text{-}22)$$

where:

X_b = X coordinate of beginning of possible engagement segment

Y_b = Y coordinate of beginning of possible engagement segment

X_e = X coordinate of ending of possible engagement segment

Y_e = Y coordinate of ending of possible engagement segment

X_p = X coordinate of a range intercept point

Y_p = Y coordinate of a range intercept point

5. Excluding Irrelevant Range Intercept Points. Range intercept points may be generated, by the foregoing process, which are irrelevant to this possible engagement segment of the flight leg. Such point pairs must be excluded from consideration on this segment, since they are considered on either prior or subsequent segments. To identify and exclude such point pairs, it is determined whether the intercept points lie on the engagement segment or on extensions thereof. If both points lie outside the same end of the possible engagement segment they are clearly excludable, since they are properly considered in another segment. If the points straddle this possible engagement segment they cannot be excluded.

6. Calculating Times of Start and End of Range Intercept. If both range intercept points fall within the possible engagement segment, their times can be calculated directly. If, however, one point is within and the other point is outside, or if the points straddle the segment, an adjustment is necessary.

a. Both Intercept Points Within Segment. If both range intercept points lie within the possible engagement segment, the time for each, t, is calculated by the expression:

$$t = b + f \cdot d/s \qquad (10\text{-}23)$$

where:

b = time of beginning of this possible engagement segment

f = the fraction of distance, between beginning and end of the segment, at which the point lies

d = the length of the segment (see Paragraph e(4)(c), above)

s = speed of the air unit.

b. One Point Within Segment. If only one of the two points lies within the possible engagement segment, time for the inside point is calculated as in the preceding paragraph. Time for the outlying point, however, is set equal to the time of the end of the segment on which the point lies outside.

c. Points Straddling Segment. If the two range intercept points straddle the possible engagement segment, the time of each point is set equal to the time of that end of the segment outside which the point lies.

7. Calculating Time Delays to Start of Projectile Intercept. Depending upon the specific circumstances, a delay may occur which affects the time at which projectiles from the given weapon type intercept the air unit. Up to three types of time delay may be included in the total delay

imposed. These types are detection delay, fire/launch delay, and time of projectile flight to target. Means used to calculate these delays are described in this paragraph. The determination of the applicability of and method of applying any or all of these delays is discussed in a later paragraph, 3e(4)(f)8, below.

a. Detection Delay. In those circumstances where detection delay is applicable, it is calculated from data provided in input tables. The input tables contain data on probability of detection of aircraft by one AD weapon, within some cutoff time, and corresponding data on median time delay, from entry of the target into line of sight until detection of the target. Some of the data can be obtained from CDCEC test results. Data are provided for three basically different types of engagement situation which the model may be called upon to simulate. Means of detection used and other conditions are assumed to be inherent to each of the three types of engagement situation. These types are:

- AD guns and short range missiles against average type helicopters at nap-of-the-earth altitude, with average background clutter/contrast for the territory being gamed.

- AD guns and short range missiles against average type fixed-wing aircraft, under average conditions.

- Medium and long range AD missiles against average type fixed-wing aircraft, under average conditions.

Data are provided for groups of two, five, and ten aircraft, each at four slant ranges. For a specific situation, the model interpolates linearly between the input data points to obtain the specific input median delay value for one AD weapon. Since an ADCU may contain a number of AD weapons which are in a position to detect, the model must adjust the input delay for this number. Also, since the field test data are often subject to a cutoff time and therefore incomplete, adjustment must be made for the missing data reflected by a probability of detection, within cutoff time, of less than 1.0. These adjustments, and the selection of a specific delay value, assume that detection delays are, in reality, lognormally distributed. Also, it is assumed that the standard deviation (in the log domain) of the distribution can be satisfactorily estimated by the relationship:

$$s = \gamma \cdot \ln(t) \qquad (10\text{-}24)$$

where:

s = estimated standard deviation (in log domain)

t = median detection delay

γ = a constant for the type of data situation being considered. This constant can be derived from field test data. Examination of data from the CDEC 43.6 test yields a value of about 0.25.

The adjustment for incomplete field test data is then made by the equation:

$$t_{1a} = t_1 \cdot e^{-S_1 \cdot f_1 (Pd/2)} \qquad (10\text{-}25)$$

where:

t_{1a} = adjusted median detection delay for one AD weapon

t_1 = input median detection delay for one AD weapon

S_1 = estimated standard deviation for the field test data (in log domain)

P_d = probability of detection by one AD weapon, within the cutoff time of the field test data.

f_1 = a function which returns an approximation[7] of the cumulative area beneath the normal curve corresponding to a position along the curve, in standard deviations, represented by the value in the parentheses. Utility function DNORM is used.

The adjustment for the actual number of observing AD weapons is then made by a method of successive approximations, using the following formula for the cumulative lognormal probability distribution:

$$\Phi(x) = \int_{-\infty}^{x} e^{-\frac{x^2}{2}} \cdot dx \qquad (10\text{-}26)$$

7. Adapted from Hastings, Approximations for Digital Computers, Princeton University Press, 1955, p. 187.

where:

$$x = \frac{\ln\left(\frac{t_n}{t_{1a}}\right)}{S_1}$$

t_n = median detection delay for n AD weapons

t_{1a} = adjusted median delay for one AD weapon

S_1 = estimated standard deviation for the test data

A trial value of t_n (actually $t_{1a/n}$) is inserted in this equation. The formula is evaluated, and the resulting value of $\Phi(x)$, representing the probability of detection by one weapon within time t, is then transformed to an estimate of the probability for n weapons, P_{dn}, by the formula:

$$P_{dn} = 1. - (1. - \Phi(x))^n \qquad (10\text{-}27)$$

where:

n = the total number of AD weapons in this ADCU

The value of P_{dn} is then compared with the desired value of 0.5, representing the probability corresponding to the desired median time delay. By adjusting t_n in the proper way, several reiterations yield a value of $\Phi(x)$ acceptably close to (within $\pm$.01) the desired 0.5. The latest t_n value is then used as the median detection delay for n AD weapons. The detection delay value used to establish the start of the CFS is now selected from the lognormal distribution of delays, based on the median value just derived for n AD weapons. This selection of delay is made by the equation:

$$\text{Delay} = t_n \cdot e^{S_n \cdot U} \qquad (10\text{-}28)$$

where:

t_n = median detection delay for n AD weapons

S_n = estimated standard deviation for n AD weapons

= $\gamma \cdot \ln(t_n)$ (γ = constant, see above)

U = a random normal deviate

= f_2 (a random number from a uniform distribution between 0.0 and 1.0)

and where:

f_2 = a function which returns an approximation[8] of the number of standard deviations corresponding to the cumulative fraction of area beneath the normal curve, as represented by the random number. Utility function FNORM is used.

b. Firing/Launch Delay. Firing/launch delay, when applicable, is obtained from the weapon input data and is a constant for each AD weapon type.

c. Time of Projectile Flight to Target. When applicable, time of projectile flight to target is approximated by a two-step reiteration process. The first step uses the current location of the air unit from which to calculate slant range to the ADCU center. Using this slant range, time of flight to initial target location is calculated or interpolated for the weapon. The target is then moved, according to its flight speed and direction, to the position it would have reached after projectile time of flight to the initial target location. For the second step, time of flight is recalculated or reinterpolated to the new target location. The second time of flight is then used as an approximation for delay applications. Slant range is calculated from the X, Y, Z coordinates of the air unit and the ADCU. Distance in the X, Y plane is calculated first. Difference in Z coordinates is then used to calculate slant range. Both calculations use the Pythagorean theorem. Given the slant range, time of flight for a missile is interpolated from the input data table of time of flight versus slant range for the weapon type. For guns, time of flight is calculated by the formula:

$$t = \frac{r}{v - r \cdot c} \qquad (10\text{-}29)$$

where:

r = slant range

v = muzzle velocity of the weapon type

c = projectile drag coefficient of the weapon type.

8. Adapted from Hastings, Approximations for Digital Computers, p. 192.

8. Application of Time Delays. The applicability of any of the three types of time delay to projectile intercept, as well as the method of application, depends upon the current nature and history of the engagement situation between the air unit and air defense weapons.

a. Detection Delay. Detection delay is applied whenever this ADCU must acquire the air unit. This ADCU must acquire the air unit when it has been either out of range or masked to all ADCUs immediately prior to the current possible engagement segment of the flight leg. Considered from the reverse standpoint, if another ADCU is currently engaging the air unit, or has recently acquired it and is about to engage it, the model does not apply detection delay to the ADCU currently being processed. Good communication is thus assumed between nearby ADCUs. If this ADCU must acquire the air unit, detection delay is applied directly to only the first CFS on this possible engagement segment. This delay may indirectly affect other CFS, however, since by definition they must follow the first CFS. Detection delay, when applicable, is applied to the time that the air unit enters line of sight of this ADCU. This time was calculated in Section 1 and stored for use here. The determination of whether this ADCU must acquire is made by checking on whether the last possible engagement segment of the flight path is contiguous with the possible engagement segment currently being processed. If they are contiguous, no detection delay is applied. If they are not contiguous, detection delay is applied as just described.

b. Firing/Launch Delay. A firing/launch delay is applied (added) whenever a detection delay is applied. In addition, firing/launch delay is applied if the air unit enters range of this ADCU before line of sight to this ADCU, when other ADCUs are already participating. In the latter case, it is assumed that this ADCU has been continually informed by the other participants as to the course and position of the air unit; therefore, this ADCU knows where to look, but cannot fire until the flight enters line of sight. In this case, it is assumed that detection time is negligible, but that reaction, tracking, or launch time must be applied, as represented by the input firing/launch delay. When applied independent of detection delay, firing/launch delay is added to the time of entry into line of sight, and only on the first CFS, similarly to detection delay.

c. Time of Projectile Flight to Target. Time of projectile flight delay is applied (added) only when firing/launch delay is applied, and similarly is applied only to the first CFS.

d. Total Delay. The total delay applied is the sum of the applicable delays as described above. Three total-delay cases result. Total delay in the first case is the sum of detection delay, firing/launch delay, and projectile time of flight. In the second case, the total is the sum of firing/launch delay and projectile time of flight. In the third case, the total is zero delay.

9. Screening for Intercept Duration. If any delay time is directly applied to a particular weapon type in a given ADCU, the duration of time over which projectiles from this weapon type can intercept the air unit may be affected. Other weapon types may also be indirectly affected. Since total delay is always added to time of entry into line of sight, and since line of sight time in some cases will precede the start of this possible engagement segment the start of projectile intercept time, t_s, is established for this weapon type as follows:

$$t_s = \text{Max of } (t_m \text{ or } (t_{los} + d)) \tag{10-29}$$

where:

t_m = start time of this possible engagement segment

t_{los} = time of entry into line of sight

d = total delay applied.

This time of projectile intercept start now supersedes the range intercept start time calculated earlier (Paragraph 3e(4)(f)6). Next, the time of projectile intercept start is compared with the time of range intercept end, calculated earlier. If there is no positive projectile intercept duration, this weapon type is dropped from further consideration on this possible engagement segment. The time of detection by this weapon is saved, however, for use in considering other weapon types in this ADCU. This time of detection is the base point for determing if any other weapons can, because of possible lower fire/launch and projectile flight times, intercept the target.

10. Storing Intercept Events. As each weapon type in each ADCU which can possibly engage on this subportion of the flight leg is processed, the results are temporarily stored for further processing. For each weapon type that passes the foregoing screening, four items of data are stored for each of the two intercept events, the start of projectile intercept and the end of projectile intercept. The four items stored are the identity of the ADCU, the identity of the weapon type, the event time, and a flag indicating whether the event is a start or an end event.

(g) Processing Intercept Events. When all ADCUs expected to participate on this possible engagement segment of the flight have been processed, the accumulation of resulting intercept events is sorted and analyzed to establish CFS. Within each CFS a unique set of ADCU-weapon type combinations are anticipated to have projectiles intercepting the vicinity of the air unit.

1. Ranking Intercept Events by Increasing Event Time. The accumulated intercept events are first ranked in order of increasing event time.

2. Finding CFS and Setting Event for Each to Call Section 3. The ranked intercept events, temporarily stored on a list called TEMP1, are considered one at a time, starting with the earliest event time. The first step is to compare the time of this event with the time of the last event. (Initially, before any CFS is established for this flight path, last event time is set to start of the possible engagement segment. Subsequently, last event time is stored with CFS.) If the time of this event is the same as that of the last event, and if this event is a start event, the identity of the ADCU and the identity of the weapon type are entered on a second list, called TEMP2, and the next event on TEMP1 is considered. The entry in TEMP2 signifies that the identified ADCU-weapon type combination is currently intercepting. If the second event on TEMP1 has a time larger than last event time, and if it also is a start event, a check is made to see if any ADCU-weapon combination is currently intercepting (is currently on TEMP2). If there is, a CFS record is built and stored and an event is set in the DIVWAG event scheduling system to call Section 3 of the In-flight Attrition Submodel at the time of this event from TEMP1, which is the end of the CFS. A key is sent with the call so that Section 3 can find the stored CFS record. This record contains four items of data. The items are last event time, event time, identity of ADCU, and identity of the AD weapon type. The ADCU and AD weapon data are copied from TEMP2, to include as many ADCU-weapon type combinations as are currently intercepting. After setting the DIVWAG event, the value of the last event time is updated to that of the event still being processed and, if this event from TEMP1 is a begin event, it is added to TEMP2. If, however, this were an end event, and if its same ADCU-weapon type combination were on TEMP2, then the counterpart on TEMP2, would be removed, signifying that that ADCU-weapon type combination is no longer intercepting. The next event from TEMP1 is then considered. If any event from TEMP1 has an event time which is not larger than the last event time, it is simply added to TEMP2 in the manner already described. Thus, all ADCU-weapon type combinations currently intercepting are kept listed on TEMP2. Whenever an event with a different time from TEMP1 is encountered, then the resulting CFS record contains all the ADCU-weapon type combinations intercepting on that CFS. This process is continued until all events on TEMP1 are exhausted, and all CFS are thus established, for this possible engagement segment of the flight path. In case no CFS is found, last event time is set to the end of this possible engagement segment.

(h) Setting Event to Call Section 1 at Last Event Time. When all events on TEMP1 are processed, an event is set in the DIVWAG event scheduling system to call Section 1 at the time of the last TEMP1 event. This event will trigger generation of the next possible engagement segment of the flight leg. This pass through Section 2 is now completed.

(5) Section 3 Operating Details. Section 3 of the In-flight Attrition Submodel is the last section. It calculates aircraft losses incurred on a single Constant Fire Subsegment (CFS), which was established at an earlier time in Section 2. The CFS is a relatively short segment of the flight over which projectiles from a unique set of ADCU-weapon type combinations were anticipated to be intercepting the air unit. Section 3 is called by the DIVWAG event-scheduling system at the end time of the CFS.

(a) Incoming Data. Data accompanying the call to Section 3 are the same as for Sections 1 and 2, with one exception. The call to Section 3 carries an additional item, which specifies where to find the stored identities of the ADCU-weapon type combinations anticipated to be participants on the CFS. Section 3 then obtains the additional information it needs. This information includes the Unit Status File of the air unit, all data stored earlier by Sections 1 and 2, a list of all AD weapon types, the Unit Status File of each ADCU involved on this CFS, suppression time durations, AD weapon characteristics, and aircraft data.

(b) Establishing Coordinates of CFS. Coordinates of the beginning and ending of this CFS are established by Section 3, using from stored data the coordinates of the possible engagement segment, the start time of the possible engagement segment, the speed of the aircraft, and the start and end times of this CFS. First, the length, d, of the possible engagement segment is calculated by the Pythagorean theorem. Next, the ending time, t_{me}, of the possible engagement segment is calculated by the equation:

$$t_{me} = t_{mb} + d/s \qquad (10\text{-}30)$$

where:

t_{mb} = beginning time of the possible engagement segment

d = length of the possible engagement segment

s = speed of the air unit

Then, the fraction, f_1, of the possible engagement segment between its beginning and the beginning of the CFS is computed by the formula:

$$f_1 = (t_{ib} - t_{mb}) / (t_{me} - t_{mb}) \qquad (10\text{-}31)$$

where:

t_{ib} = beginning time of the CFS

t_{mb} = beginning time of the possible engagement segment

t_{me} = ending time of the possible engagement segment

The fraction, f_2, of the possible engagement segment between its beginning and the end of the CFS is calculated by substituting the time of the ending in place of time of beginning of the CFS in the foregoing formula. Using these fractions, the coordinates of the CFS ends are calculated by the equations:

$$X_{ib} = X_b + f_1 \cdot (X_e - X_b) \qquad (10\text{-}32)$$

$$Y_{ib} = Y_b + f_1 \cdot (Y_e - Y_b) \qquad (10\text{-}33)$$

$$X_{ie} = X_b + f_2 \cdot (X_e - X_b) \qquad (10\text{-}34)$$

$$Y_{ie} = Y_b + f_2 \cdot (Y_e - Y_b) \qquad (10\text{-}35)$$

where:

X_b = beginning X coordinate of the possible engagement segment

Y_b = beginning Y coordinate of the possible engagement segment

X_e = ending X coordinate of the possible engagement segment

Y_e = ending Y coordinate of the possible engagement segment

f_1 = fraction of possible engagement segment to start of CFS

f_2 = fraction of possible engagement segment to end of CFS

X_{ib} = beginning X coordinate of the CFS

Y_{ib} = beginning Y coordinate of the CFS

X_{ie} = ending X coordinate of the CFS

Y_{ie} = ending Y coordinate of the CFS

(c) Processing Each Participating ADCU. More than one ADCU may have been anticipated to be a participant on this CFS. If so, the ADCUs are processed one at a time. This processing considers first those factors common to all AD weapon types within an ADCU. These factors include AD suppression conditions, the dispatching of escort aircraft to suppress this ADCU, and the geometry of the CFS as viewed from this ADCU. Next, each weapon-type anticipated to be a participant, from this ADCU, is processed to determine its effects against the air unit.

1. AD Suppression Check. To determine whether the AD weapons in this ADCU were suppressed during any part of this CFS, two sources of suppression are considered. One source considered is escort aircraft. The other source considered is TACAIR or ground-based artillery. The most recent interval during which all AD weapons in the ADCU are assumed to be suppressed is calculated for each of these two sources. The two intervals are compared with the CFS to see if overlap occurs. If overlap does occur, the fraction of the CFS overlapped is calculated for later use. If the CFS is totally overlapped, the ADCU is considered not to be firing.

a. AD Suppression by TACAIR or Ground Artillery. To establish the most recent interval for AD suppression by TACAIR or ground-based artillery, the time of last assessment by the Area Fire Model is obtained from the Unit Status File of the ADCU. This time is considered to be the start of the suppression interval. Next, an input ADCU suppression time duration is obtained from the suppression time tables (see Volume VI, Chapter 12), for each of TACAIR and artillery, according to the unit type (UTD), of the ADCU. These two input values are averaged and added to the start of the suppression interval to yield the end of the suppression interval for TACAIR or ground-based artillery.

b. AD Suppression by Escorts. Each time an escort pair is dispatched, as described below, to suppress an ADCU, an input ADCU suppression time duration is applied. This time duration is obtained from the same suppression time tables referenced in the preceding subparagraph. In the case of escorts, however, this suppression time duration is applied at the time of escort dispatch, to generate a time at which escort suppression of the ADCU will lapse, t_e, by the expression:

$$t_e = t_b + t_s + {}_m \qquad (10\text{-}36)$$

where:

t_b = time at which suppression will begin

t_s = suppression time duration - input (suppression tables)

t_m = suppression mission duration - input for In-Flight Attrition

The time at which suppression will begin, t_b, is further defined as:

$$t_b = t_d + t_r$$

where:

t_d = time of of escort pair dispatch to suppress ADCU

t_r = response time of escorts to reach and attack ADCU - input for In-flight Attrition

The times at which escort suppression will lapse, t_e, and start, t_b, are stored on the Unit Status File of the ADCU; therefore, when Section 3 seeks to check the most recent interval for escort suppression, these two values are obtained from the ADCU Unit Status File.

c. Joint Suppression. The combined suppression for escorts and for TACAIR or ground-based artillery is formed through several logic steps. The simplest case is where the suppression interval for TACAIR or ground-based artillery overlaps the suppression interval for escorts. In this case, a joint suppression interval can be formed, consisting of the earliest of the two interval starts and the latest of the two interval ends. This joint interval is then rectified (truncated, if necessary) so that only that portion which overlaps the CFS is considered further. The fraction, f, of the CFS overlapped by the joint suppression interval is then calculated by the expression:

$$f = (t_{se} - t_{sb}) / (t_{ie} - t_{ib}) \qquad (10\text{-}37)$$

where:

t_{se} = rectified ending time of joint suppression interval

t_{sb} = rectified beginning time of joint suppression interval

t_{ie} = ending time of CFS

t_{ib} = beginning time of CFS

If, however, the suppression interval for TACAIR or ground-based artillery does not overlap the suppression interval for escorts, further logic steps are necessary. Each interval is compared with the CFS to see if any overlap occurs. If neither interval has any overlap, the fraction, f, is set to zero. If one interval has overlap, but the other does not, the former interval is rectified and used in the same way as in the simplest case to calculate the overlap fraction, f. If both intervals have some overlap,

each interval is independently rectified and its overlap fraction calculated as described above. The two fractions are then summed to yield the joint overlap fraction. The joint overlap fraction is used in the suppression check, next paragraph, and also later in calculating the number of weapons able to fire.

d. Suppression Check. If the joint suppression overlap fraction is 1.0. no AD weapons in this ADCU are considered to fire during this CFS; therefore, since the ADCU is not firing AD weapons, escorts will not be dispatched to suppress it, and the ADCU is not processed further on this CFS.

2. Decision to Dispatch Escorts. If the ADCU is firing, several checks are made to determine whether a pair of escort aircraft should be dispatched to suppress the ADCU.

a. Has Air Unit Passed Beyond No Request Point? If at the beginning of the CFS the air unit has passed beyond the "no request point," escorts are not dispatched. Whether the air unit has passed beyond the "no request point" is determined with the help of utility routine POINTLIN. This routine is given the X, Y coordinates of the beginning and ending of this possible engagement segment of the flight path and the X, Y coordinates of the ADCU. POINTLIN returns a value, T_1, which represents the position of the ADCU along the flight path relative to the beginning and ending of the segment. The value of T_1 returned is negative if the ADCU is off the beginning. Between the beginning and ending of the segment, the value of T_1 varies from zero to 1.0, representing the fractional position of the ADCU along the segment. Beyond the ending, the value of T_1 increases in the positive direction. The "no request point," meanwhile, is based on the beginning of CFS. For comparison with T_1, a value, T_2, representing the position of the "no request point" is generated by the expression:

$$T_2 = (t_{ib} - t_{mb} - t) \ / \ (d/s) \qquad (10\text{-}38)$$

where:

t_{ib} = beginning time of the CFS

t_{mb} = beginning time of the possible engagement segment

t = the length of time after passing the ADCU beyond which escorts would not be sent back to suppress it, from input data

d = the length of the possible engagement segment

s = speed of the air unit

The two values are now compared, and if $T_2 > T_1$, the air unit is considered beyond the "no request point," and escorts are not dispatched.

b. Is ADCU Too Far Away From Flight Path? If the ADCU is located at a distance from the flight path which exceeds the maximum distance which escorts are permitted to direct to attack plus any standoff distance of the escort munition to be employed, escorts are not dispatched to suppress this ADCU. The distance from the ADCU perpendicular to the flight path is another value returned by utility routine POINTLIN, just employed as described in the preceding paragraph. The distance which escorts are permitted to direct plus their munition standoff distance are combined in a single input value, used in this comparison.

c. Are Escorts Available? If a pair of escorts does not remain on hand, according to the Unit Status File of the air unit, escorts are not dispatched. If escorts are dispatched, no adjustment is currently made to the number available.

d. Dispatch of Escorts. If the three preceding questions are all answered positively, a pair of escorts is considered dispatched to suppress the firing ADCU. The suppressive effect of this attack by escorts is recorded on the Unit Status File of the ADCU, as described in paragraph 3e(5)(c)1 b, above.

3. Geometry to Midpoint of CFS:

a. Midpoint of the CFS. The midpoint of the CFS is established using the coordinates of the beginning and ending of the CFS as calculated at the beginning of Section 3. The X and Y coordinates of the midpoint are each calculated as one-half the sum of the corresponding begin and end coordinate of the CFS. The Z coordinate of the midpoint is then obtained for the X, Y coordinate by use of the utility routine ELEVATE.

b. Aspect Angles and Slant Range. Both the horizontal and vertical angles from the ADCU to the air unit are calculated. The horizontal aspect angle has its apex at the ADCU and is measured between the point on the flight path nearest the ADCU (the crossover point) and the air unit. The vertical aspect angle similarly has its apex at the ADCU and is measured between the air unit and the X, Y plane containing the ADCU. To calculate the horizontal aspect angle, the ground track (in the X, Y plane of the ADCU) of the flight path is used. The horizontal distance, d_m, from the ADCU to the midpoint of the CFS is computed by the expression:

$$d_m = \sqrt{(X_{im} - X_a)^2 + (Y_{im} - Y_a)^2} \qquad (10\text{-}39)$$

where:

X_{im} = X coordinate of midpoint of CFS

Y_{im} = Y coordinate of midpoint of CFS

X_a = X coordinate of ADCU center

Y_a = Y coordinate of ADCU center

The horizontal distance, d_c, from the ADCU to the crossover point is obtained by use of the utility routine DISTPL, which is given the beginning and ending X, Y coordinates of the CFS and the X, Y coordinates of the ADCU. The horizontal aspect angle, H, is then:

$$H = \sin^{-1} (d_c/d_m) \tag{10-40}$$

where:

d_c = horizontal distance from ADCU to crossover point, defined above

d_m = horizontal distance from ADCU to air unit point, defined above

To calculate the vertical angle, V, the Z coordinate of the ADCU is obtained, through the utility routine ELEVATE, given the X,Y coordinates of the ADCU. For use here and also in later steps, the slant range, r_s, from the ADCU to the midpoint of the CFS is calculated by the expression:

$$r_s = \sqrt{d_m^2 + h^2} \tag{10-41}$$

where:

d_m = as defined above

h = difference in Z coordinates of ADCU and midpoint of CFS

The vertical aspect angle, V, is then:

$$V = \sin^{-1} (h/r_s) \tag{10-42}$$

where:

h = as defined above

r_s = slant range, as defined above

c. Angular Rates of Air Unit. The rates of change in the horizontal and vertical angles from the ADCU to the air unit are calculated for comparison with the slew rate or tracking rate capability of AD weapons. The horizontal angular rate, H_r, is calculated by the expression:

$$H_r = s \cdot \text{cosine}(H)/d_m \qquad (10\text{-}43)$$

where:

s = speed of the air unit

d_m = horizontal distance from ADCU to midpoint of CFS

$\text{cosine}(H) = \sqrt{1-\text{sine}^2(H)}$

The vertical angular rate, V_r, is computed by the similar equation:

$$V_r = s \cdot \text{sine}(V)/r_s \qquad (10\text{-}44)$$

where:

s = speed of air unit

r_s = slant range

sine(v) = as defined above

d. Aircraft Direction. Also relative to the midpoint of the CFS, a determination is made as to whether the aircraft are approaching or leaving the ADCU. This determination is made with the help of routine POINTLIN, which is given the X, Y coordinates of the midpoint and the ending of the CFS and the X, Y coordinates of the ADCU. If the value of the variable returned which relates the position of the ADCU to this line segment is negative, the aircraft are leaving. Otherwise they are approaching.

e. Presented Area of Each Aircraft Type. For each type of aircraft in the air unit, the area of one aircraft, as presented to the ADCU, is calculated for the midpoint of the CFS. Input data provides the face-perpendicular areas of the front or rear, side, and bottom of each aircraft type. The area, A_p, presented to the ADCU, from the midpoint, for a given aircraft type, is calculated by the equation:

$$A_p = A_1 \cdot \text{cosine}(V) \cdot \text{sine}(H) + A_2 \cdot \text{cosine}(V) \cdot \text{cosine}(H) + A_3 \cdot \text{sine}(V) \qquad (10\text{-}45)$$

where:

A_1 = area of front or rear

A_2 = area of side

A_3 = area of bottom
sines and cosines of angles are as defined above
or derived therefrom

f. Fraction of ADCU in Line of Sight. To determine the fraction of the ADCU (and its contained AD weapons) which have line of sight to the air unit on this CFS, a method is used which should provide approximate answers of the right magnitude. This method was developed for this model, without benefit of empirical data, and should be considered an interim method. To apply this method, the terrain cell containing the ADCU is identified, and the corresponding values of the terrain indices, roughness-vegetation, and forestation, are obtained. The utility routine IOTERN is given the X, Y coordinates of the ADCU to provide these values. Next, the vertical angle from the ADCU to the air unit, defined above, is calculated in degrees by the expression:

$$V_d = \tan^{-1} (\text{sine}(V)/\text{cosine}(V)) \cdot 57.3 \qquad (10\text{-}46)$$

If the vertical angle, V_d, is greater than 45 degrees, the fraction, f_{los}, of the ADCU in line of sight is calculated by the formula:

$$f_{los} = 1.05 - 0.05 \cdot RV \qquad (10\text{-}47)$$

where:

RV = roughness-vegetation index, with values ranging from 1-9 (see Chapter 2)

If the vertical angle is less than or equal to 45 degrees, the fraction in line of sight is computed by the formula:

$$f_{los} = 0.55 + 0.05(1. + V_d/5.) - 0.05 \cdot RV \qquad (10\text{-}48)$$

where:

RV = as defined above

V_d = as defined above

Finally, in either case, if the terrain cell is forested (i.e., if the forestation index value is greater than zero), one-half of the fraction calculated above is taken for the fraction of the ADCU in line of sight to the air unit.

(d) Processing Each Participating Weapon Type in the ADCU. Within each ADCU which passes the foregoing tests, each AD weapon type anticipated to be a participant on this CFS is processed to determine its possible effects against the air unit. This processing includes rechecking for weapons on hand, checking the air unit angular rate against weapon slew rate, and determining the fraction of the ADCU in range of the air unit, with subsequent separate processing of missile weapons, as distinguished from gun weapons.

1. Check for Weapons on Hand. The number of weapons on hand of this type is obtained from the current Unit Status File of the ADCU. If no weapons remain, this weapon type is not considered further, and the next weapon type is considered.

2. Slew Rates Check. If weapons are on hand, the angular rates of the air unit are compared with the maximum slew rates of the weapon type, from the input data. If the rate of change of either the horizontal or vertical angle from the ADCU to the air unit, as calculated earlier, exceeds the respective maximum slew rate of the weapon, this weapon type is not considered further.

3. Fraction of ADCU in Degraded Range. To determine the fraction of the ADCU weapons of this type which are within range of the midpoint of the CFS, the maximum effective range of the weapon, from input, is adjusted for any degradation which may be caused by current weather-visibility conditions, as expressed by the DIVWAG visibility index, whose value varies from 1 to 9 (see Chapter 2). Input data for the weapon provides capability degradation percentages for five categories of weather-visibility index, WV. These categories are defined as Very Poor (WV = 1-2), Poor (WV = 3-4), Intermediate (WV = 5-6), Fair (WV = 7-8), and Good (WV = 9). The respective degradation percentage, d_p, is applied to the maximum effective range, r_m, of the weapon to obtain adjusted effective range, r_a, by the expression:

$$r_a = r_m \cdot (1.-d_p) \tag{10-49}$$

The Z coordinate of the ADCU is obtained by function ELEVATE, which is given the X, Y coordinates. The radius of the circle on whose circumference the AD weapons are assumed to be uniformly distributed is calculated as one-half the lesser of ADCU width or depth. The X,Y,Z coordinates of the ADCU and the radius of weapon location in the ADCU is given to utility function CIRCLE, together with the X, Y, Z coordinates of the midpoint of the CFS and the adjusted effective range of the weapon. CIRCLE returns the fraction of the weapon location circle which lies within a slant distance, r_a, of the midpoint

of the CFS. If this fraction is zero, this weapon type is not considered further.

4. Net Number of Weapons Intercepting. This processing step combines a number of factors generated in prior steps with system reliability and ECM degradation factors to yield the net number of weapons intercepting on this CFS. This processing is based upon the gross number of weapons of this type on hand in this ADCU at the time of the last inventory. The model currently takes the last inventory at the end of the CFS, although ideally the inventory should be taken at the beginning of the CFS and losses during the segment prorated.. The various factors are applied to this gross number to yield the net number, according to the equation:

$$W_n = W_g \cdot (1-f_d) \cdot (1-f_s) \cdot f_{los} \cdot f_r \cdot R \cdot (1-f_e) \qquad (10\text{-}50)$$

where:

W_n = net number of weapons intercepting

W_g = gross number of weapons on hand at last inventory

f_d = fraction of weapons destroyed since last inventory (currently set=0)

f_s = fraction of weapons suppressed during the CFS as defined in paragraph 3e(5)(c)1c, above

f_{los} = fraction of weapons in line of sight, as defined in paragraph 3e(5)(c)3f, above

f_r = fraction of weapons in degraded range, as defined in paragraph 3e(5)(d)3, above

R = system reliability factor, from input

f_e = ECM degradation percentage, from input

If the net number of weapons intercepting is less than 0.5, this weapon type is not considered further.

(e) Further Processing of Missile Weapons. If a missile weapon type passes the foregoing tests, the probability of kill values, for a single missile, are linearly interpolated from an input table for this missile type, according to a calculated missile miss distance against a single aircraft. The four categories of kill, as defined above, are considered. Each of the net number of weapon systems, as defined in the preceding paragraph, is assumed to fire one missile. Refinement of this assumption, through consideration of rate of fire limitations, may be added

at a later date. The number of missiles fired is then multiplied by the probability of kill values to yield losses. The assumption is made that each missile is directed at a single aircraft, and that a relatively few missiles are fired from this ADCU on this CFS. Missiles fired are subtracted from the Unit Status File of the ADCU.

1. Calculation of Miss Distance. The model currently uses as input an average missile guidance error for this weapon type. It is assumed that errors in both dimensions are equal and independent; therefore, the standard deviation of the error, for a Rayleigh distribution, is given by the formula:

$$s = \frac{a}{\sqrt{\frac{\pi}{2}}} \qquad (10\text{-}51)$$

where:

s = one standard deviation

a = average error

A distance is then selected from a normal distribution by the expression:

$$d = S \cdot F(R_n) \qquad (10\text{-}52)$$

where:

S = as defined above

R_n = a random number between 0 and 1.

F = a function which returns the position on the normal curve, in standard deviations, corresponding to the cumulative area represented by the random number (utility function FNORM).

The distance selected is then adjusted to miss distance by subtracting a radius extracted from the presented area of the aircraft fired upon.

2. Aircraft Losses. Based on the calculated miss distance, probability of kill values for one missile against one aircraft are linearly interpolated from input for the type of aircraft attacked. The type attacked is assumed to be the type having the largest presented area in the air unit. Losses for each of the four kill type categories are, tentatively, the product of interpolated probability of kill and number of missiles fired, as defined above. Later integration of these values with gun effects limits

these loss values to the number of aircraft on hand of that type.

(f) Further Processing of Gun Weapons. If a gun weapon type passes the tests up to this point, it is processed further to yield probability of kill values and to combine these values with the values of other gun systems in the form of cumulative or compound probabilities of survival of a single aircraft to gun systems. This processing includes calculation of the number of rounds intercepting the air unit, the number of rounds per aircraft, the vulnerable areas of the aircraft at the aspect angles and projectile striking velocity of the midpoint of the CFS, estimation of gun weapon errors and probable hits, and finally the determination of probabilities of kill and compound probabilities of survival for each of the four kill categories.

1. Number of Rounds Intercepting Air Unit. The number of rounds from this weapon type, in this ADCU, that will intercept the air unit is based on the net number of weapons, defined above, and the rate of fire and possible reload delays that may occur on this CFS. First, an average rate of fire, without reload delay, is calculated by the formula:

$$R = b_n \Big/ \left(\frac{b_n}{b_r + b_d} \right) \tag{10-53}$$

where:

R = average rate of fire, without reload delay, for one weapon

b_n = number of rounds per burst, from input for this weapon type

b_r = burst rate of fire, rounds per unit time, from input

b_d = interburst delay time, from input.

Next, the time required to exhaust magazine capacity at the above rate is calculated by the expression:

$$t_{mag} = C/R \tag{10-54}$$

where:

t_{mag} = time to exhaust magazine capacity at rate R

C = capacity of magazine, in rounds, from input

R = rate, as defined above.

The number of reloads required, N_{re}, is calculated by the equation:

$$N_{re} = t_{is} \Big/ \left(t_{mag} + t_{re} \right) \tag{10-55}$$

where:

t_{is} = time length of the CFS

t_{mag} = time to exhaust magazine capacity, as defined above

t_{re} = reload delay, from input

Firing time at average rate without reloads, t_{fa}, is calculated by the expression:

$$t_{fa} = t_{is} - N_{re} \cdot t_{re} \qquad (10\text{-}56)$$

where:

t_{is} = as defined above
N_{re} = number of reloads required, as defined above

The number of rounds, N, intercepting the air unit is then calculated by the equation:

$$N = R \cdot t_{fa} \cdot W_n \qquad (10\text{-}57)$$

where:

R = average rate of fire without reload, as defined above

t_{fa} = firing time at average rate without reload, as defined above

W_n = net number of weapons intercepting

The number of rounds, N, is then limited to the number of rounds of ammunition on hand of this type in this ADCU, as obtained from the ADCU Unit Status File. This same number of rounds is also subtracted from the Unit Status File to represent ammunition expenditures.

2. Number of Rounds Per Aircraft. For guns, it is assumed that the rounds intercepting are equally distributed over the number of aircraft of all types in the air unit at the start of the CFS. The number of rounds intercepting per aircraft, N_a, is then:

$$N_a = N/A \qquad (10\text{-}58)$$

where:

N = number of rounds intercepting air unit, as defined above

A = number of aircraft of all types in the air unit.

3. Vulnerable Areas of Aircraft. Aircraft vulnerable area data are basic input for calculation of gun weapon type probabilities of kill. Currently, Section 3 uses as input the same average vulnerable area data as used by the ENRATA portion of the Air Ground Engagement Model. These data comprise a single vulnerable area value for each of four kill categories, within each weapon type-aircraft type combination. Since the values for the four kill categories are embedded one within another in a cumulative fashion, the individual values must be extracted before use in Section 3. These data are averages, assuming an average aspect angle and an average slant range. Section 3 is designed, however, to utilize, at some later date, detailed vulnerable area data tables. Such tables contain data for seven striking velocities and for each of the faces of the aircraft (front, rear, top, bottom, and side). To interpolate vulnerable area data from such tables, at some later date, striking velocity against a stationary target, V_{st}, is calculated by the formula:

$$V_{st} = V_m / \left(1.+f_d \cdot t_f\right)^2 \qquad (10\text{-}59)$$

where:

V_m = muzzle velocity of the weapon, from input

f_d = ballistic drag coefficient, from input

t_f = time of flight of projectile, calculated as described in Section 2

Striking velocity against the moving target, V_{mt}, is then derived from the stationary situation by the folmula:

$$V_{mt} = V_{st} + f \cdot \text{sine}(H) \cdot \text{consine}(V) \cdot s \qquad (10\text{-}60)$$

where:

V_{st} = as defined above

f = either minus 1 or plus 1, depending on aircraft direction

H = horizontal aspect angle, as defined above

V = vertical aspect angle, as defined above

At some later date, interpolated vulnerable areas of each face can be consolidated into one area, using the expression:

$$A = A_{vf} \cdot \text{cosine}(V) \cdot \text{sine}(H) + A_{vr} \cdot \text{cosine}(V) \cdot \text{sine}(H) + A_{vs} \cdot \text{cosine}(V) \cdot \text{cosine}(H) + A_{vb} \cdot \text{sine}(V) \qquad (10\text{-}61)$$

where:

A_{vf} = front vulnerable area (zero if aircraft leaving)

A_{vr} = rear vulnerable area (zero if aircraft approaching)

A_{vs} = side vulnerable area

A_{vb} = bottom vulnerable area

4. Weapon Error. Four separate sets of equations, from the AMHI study, are used to approximate the weapon error associated with four types of gun system. These four types of system are, (1) visually sighted 12.7mm or .50 cal mg, (2) optically directed 14.5mm, 23mm, and 57mm systems, (3) range-only radar systems, and (4) full-solution radar systems. These equations account for aiming errors and ballistic dispersion errors. Parameters used by these equations include slant range, as defined above, aircraft speed, target angular rate, and projectile time of flight, as defined above. Target angular rate is taken here to be the maximum of the horizontal or vertical rates, as defined above. An item in the weapon input data designates which equation set is used. The result of these equations is a standard deviation in square meters. On an experimental basis another equation, from the ADAFSS study, is used to approximate target maneuver error. This equation uses aircraft speed, projectile time of flight, and a data input representing an average evasive maneuver turn acceleration rate. This equation also yields a standard deviation in square meters. Total error standard deviation used for hit calculations, is then the square root of the sum of the squares of the components in square meters. The AMHI equations used can be found on pages F-19, F-20, F-21, and F-46, Annex F, of the USACDC study, Airmobility in the Mid/High-Intensity Environment (AMHI)(U), January 1971. The ADAFSS equation can be found on page 4, and addendum, to Attachment IV of an ICAS(CDC) compilation (ICAS301-71) titled Documents Related to Army Direct Aerial Fire Support System (ADAFSS).

5. Probability of Hit. The probability of hit by one round from the gun weapon type is calculated by the equation:

$$P_{h1} = 1.-e^{-A_p\Big/\left(2\pi\cdot E^2\right)} \qquad (10\text{-}62)$$

where:

P_{h1} = the probability of hit by one round against this aircraft type

A_p = presented area of this aircraft type, as defined above

E = total weapon error, in square meters

The probability of hit is calculated against each type of aircraft in the air unit.

6. Probability of Kill. Probability of kill by one round from the weapon type is calculated by the expression:

$$P_{k1} = P_{h1} \cdot \left(\frac{A_v}{A_p}\right) \qquad (10\text{-}63)$$

where:

P_{k1} = probability of kill, this kill category, this aircraft type, by one round

P_{h1} = probability of hit, as defined above.

A_v = vulnerable area of this aircraft type to this weapon, as defined above

A_p = presented area of this aircraft type, as defined above.

The probability of kill by the number of rounds per aircraft is evaluated by the expression:

$$P_{kna} = 1.-(1.-P_{k1})^{N_a} \qquad (10\text{-}64)$$

where:

P_{kna} = probability of kill, this kill category, this aircraft type, by number of rounds per aircraft

P_{k1} = probability of kill by one round, as defined above

N_a = number of rounds per aircraft, as defined above

7. Compound Probability of Survival. The probabilities of survival are compounded, for each gun weapon type intercepting, as each gun weapon type is processed. These compound probabilities of survival, for each kill category and each aircraft type in the air unit, are for use in the final loss calculations. The compound probabilities of survival, starting with a value of 1.0, are calculated by the expression:

$$P_{sp} = P_{sp} \cdot (1.-P_{kna}) \qquad (10\text{-}65)$$

where:

P_{sp} = compound probability of survival, this aircraft type, this kill category, to date

P_{kna} = probability of kill, as defined above.

(g) Final Loss Calculations. Final loss calculations combine missile effects and gun effects. Aircraft losses to missiles, as described

in Paragraph 3e(5)(e)2 above, and limited to the number of aircraft on hand of the type attacked, are subtracted from the aircraft on hand in the air unit, before gun losses are calculated. Losses to guns are then computed by applying the probabilities of survival, compounded over all intercepting gun weapon types, to the remaining aircraft of each type. Gun losses are computed by the equation:

$$L = A \cdot (1. - P_{sp}) \qquad (10\text{-}66)$$

where:

A = number of aircraft remaining on hand of this type, after prior kill subtraction

P_{sp} = compound probability of survival, this aircraft type, this kill category, as defined above

Troop and cargo losses are subtracted from the air unit in proportion to A and B kills.

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CHAPTER 11

NUCLEAR ASSESSMENT MODEL

1. MILITARY ACTIVITY REPRESENTED:

a. The Nuclear Assessment Model assesses the effects of tactical nuclear weapons against personnel, materiel, and barriers and facilities. The magnitude of the energy released in a nuclear explosion exceeds enormously the energy released in a nonnuclear explosion. Transfer of energy from the weapon to the surrounding media begins with the actual nuclear explosion and is exhibited as three distinct effects:

(1) Blast. Mechnical shock effects are produced by a high-pressure impulse or wave as it travels outward from the burst.

(2) Thermal Radiation. Heating effects result as objects in the surrounding area absorb thermal energy released by the burst.

(3) Nuclear Radiation. Ionizing effects are produced when nuclear radiation emitted by the burst is absorbed.

b. Two specific types of information pertaining to the military use of nuclear weapons have been developed through weapon tests.

(1) The thermal, blast, or nuclear radiation levels required to cause a particular degree of damage to a materiel or a personnel target element.

(2) The distance to which the required levels will extend from a given weapon.

c. Although the Nuclear Assessment Model does not explicitly consider the discrete weapon effects, the use of test data provides for a reliable assessment of the combined effects of thermal, blast, and nuclear radiation within the validity factors associated with the data.

d. The actual delivery of tactical nuclear weapons requires targeting, scheduling, and laydown of weapons that cannot be simulated by the current DIVWAG Model as an automatic feature in the same manner that nonnuclear fires are simulated. In tactical nuclear warfare, a potential nuclear target is analyzed for its composition; a desired level of damage is derived; a yield, height of burst, and ground zero for the nuclear weapon to produce the desired level of damage is determined; a delivery system is selected; troop safety limits are checked; and the weapon is scheduled and fired. Once the weapon is fired, the actual ground zero, yield, and height of burst are calculated, and the effects of the weapons on military targets are assessed. The Nuclear Assessment Model simulates only the latter activities.

e. In the play of a war game simulating high intensity conflict and utilizing the DIVWAG Model, the military gamer must array forces on the battlefield according to appropriate doctrine for tactical nuclear warfare and must perform the necessary nuclear weapon targeting. Nuclear fires may then be integrated with the conventional war simulation to achieve the objectives of the game. In order to ensure optimum efficiency in using the DIVWAG Model for play of tactical nuclear games, the game periods should be short compared to periods simulating the employment of conventional munitions. Without such relatively short periods, a simulation of the less dense, more porous, and highly mobile tactical nuclear battlefield may produce distorted and non-credible results.

2. MODEL DESIGN:

a. Model Structure. The Nuclear Assessment Model processes a nuclear fire event by independently considering the weapon effect against units, obstacles, facilities, and sensors within appropriate distances from ground zero. The assessment methodology is resolved into the following five phases: location of ground zero, assessment of units (personnel and equipment, including sensors), assessment of barriers and facilities, creation of an induced radiation hazard area, and scheduling of radiation assessment. The flow through the Nuclear Assessment Model is depicted in Figure 11-1.

(1) Location of Ground Zero:

(a) Requirements for a nuclear fire event include the specification of the x and y coordinates of the desired ground zero, the location of the fire unit, the delivery system to be employed, the desired warhead, the type of fuze desired, and the desired height of burst.

(b) Associated with each delivery system and fuze type is a table of expected delivery errors as a function of weapon-target range. From the range and deflection standard deviations the range and deflection errors are calculated using two normally distributed random numbers. The probable error in height of burst is used to determine the actual height of burst, again making use of a random number from a normal distribution. The round velocity is then used to make a further adjustment in the range error of the round. Range and deflection errors are resolved into x and y components to determine the actual ground coordinates under the burst. If a round impacts (actual height of burst goes to zero or negative) and the fuze does not provide for a detonation upon impact, the round is considered a dud.

(2) Assessment of Units:

(a) Combined effects damage radii corresponding to the actual height of burst are determined by interpolating among input height of burst values. The largest radius, centered at ground zero, determines the area of search for units to be assessed. If any portion of a unit is within this area it is assessed based upon the force composition. The following target categories are assessed using appropriate damage radii.

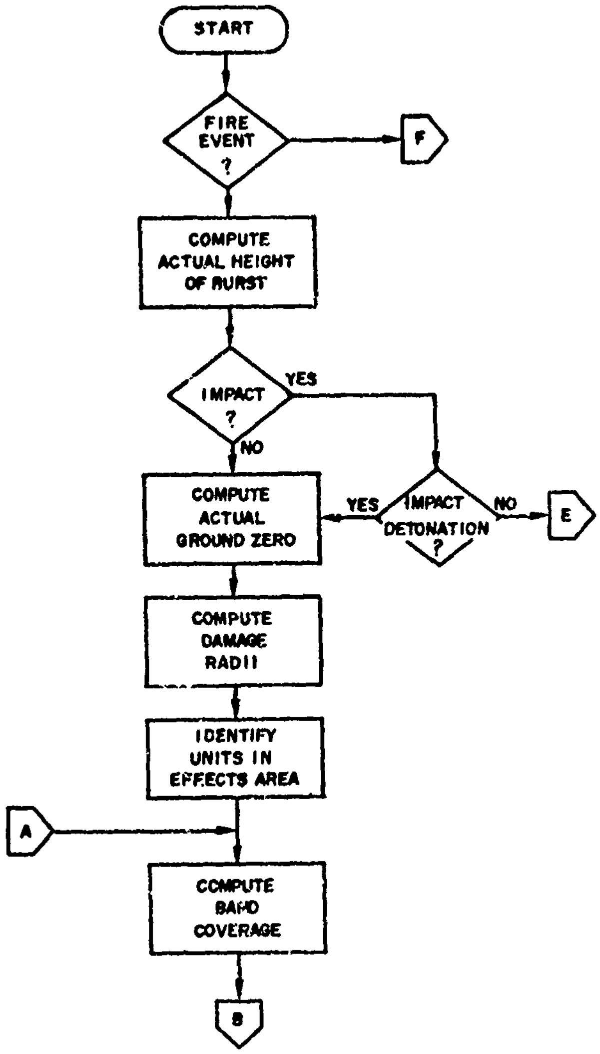


Figure 11-1. Nuclear Assessment Model Flow (continued next page)

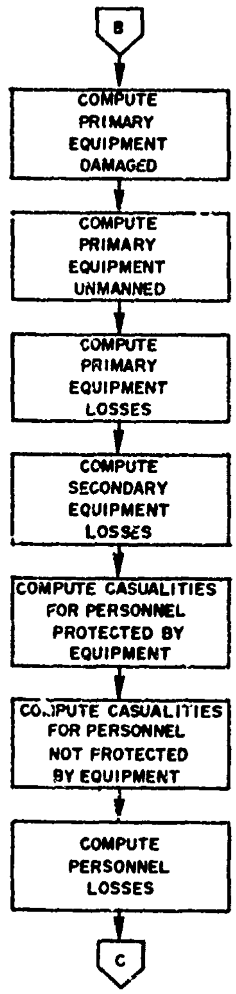


Figure 11-1. Nuclear Assessment Model Flow (continued)

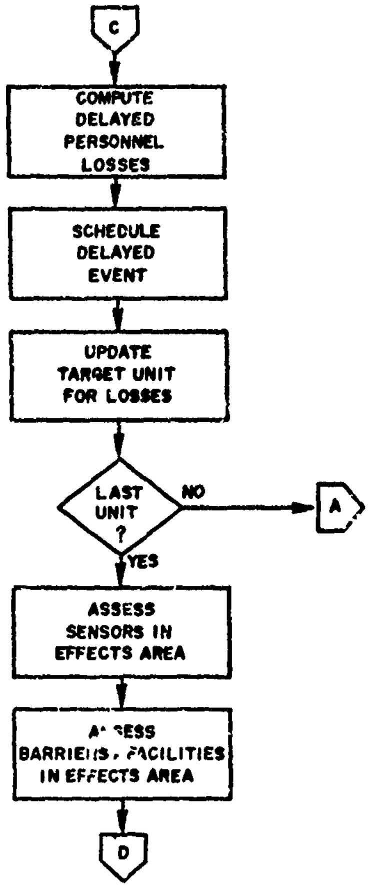


Figure 11-1. Nuclear Assessment Model Flow (continued)

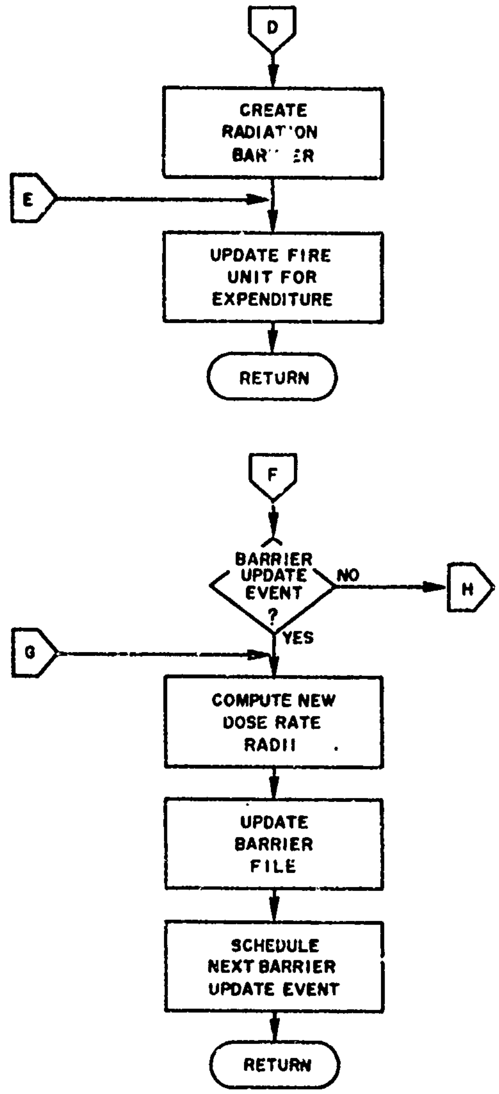


Figure 11-1. Nuclear Assessment Model Flow (continued)

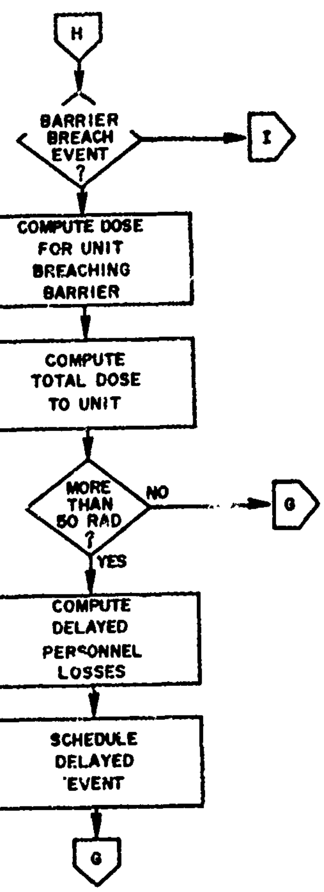


Figure 11-1. Nuclear Assessment Model Flow (continued)

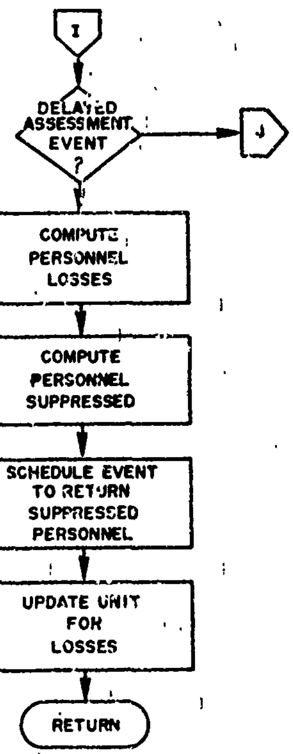


Figure 11-1. Nuclear Assessment Model Flow (continued)

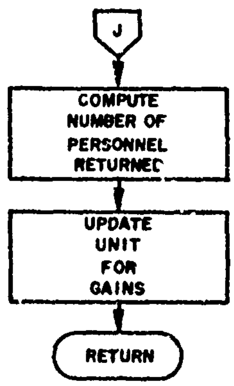


Figure 11-1. Nuclear Assessment Model Flow (concluded)

1. Exposed personnel, prompt casualties.

2. Personnel in open foxholes, prompt casualties.

3. Personnel in earth shelters, prompt casualties.

4. Personnel in APCs, prompt casualties.

5. Personnel in tanks, prompt casualties.

6. Aircraft in flight (up to four types).

7. Equipment on the ground (up to six types).

(b) Equipment of each type to be assessed has its item code linked to one of the damage radii. For each equipment type the appropriate damage circle is centered at ground zero and the overlap area of the circle with each band of the unit being assessed is determined. All equipment of each type linked to the damage radius which is contained in the area of overlap between the uniformly distributed band and the circle is considered damaged. Personnel losses are accumulated by considering the casualties per equipment item summed over all equipment losses of each type.

(c) Personnel protected by tanks, APCs, and other equipment items affording similar protection are assessed for prompt radiation when the equipment items are located outside the blast damage circle but inside the radiation damage circle for protected personnel (tanks and APCs). Prompt radiation damage circles, centered at actual ground zero, are overlayed on the unit being assessed; and casualties per equipment item are assessed for those equipment items located in the areas described. These casualties are added to the blast casualty total. This technique of assessment may leave some items of equipment unmanned. These items are identified as unmanned in a printout and are treated as equipment losses.

(d) Casualties are next assessed to unit personnel not protected by equipment. This category obviously includes all remaining personnel in the unit, which are assumed to be distributed among vulnerability postures based upon unit activity and a warned or unwarned condition. For the STAY activity the distribution of personnel among postures is additionally assumed to be a function of the time spent in that activity. The following postures are considered by the model.

- Exposed - personnel in the open
- Protected - personnel in open foxholes
- Protected - personnel in covered earth shelters.

Personnel in each posture are assessed by overlaying the appropriate damage circle on each band of the unit. Casualties within each overlap area are added to the previous personnel casualty total.

(3) Assessment of Barriers and Facilities:

(a) As many as ten different damage radii are available for barrier/facility assessment, where the barrier/facility mnemonic identifies the appropriate radius to be used. Damage radii are determined by considering the actual height of burst and interpolating among input values. The largest of these radii defines the barrier/facility circle of search. Each barrier/facility within the circle of search, centered at ground zero, is included in the assessment.

(b) Each bridge within the barrier/facility circle of search is assessed by determining the fraction of the bridge within the appropriate damage circle centered at ground zero. If more than one half the bridge is contained in the circle it is considered damaged; otherwise, the bridge is considered not damaged. The barrier file is updated to reflect the assessment when damage occurs.

(c) Jungles, forests, undergrowth, towns, and minefields, when assessed, result in new types of barriers/facilities. If more than one half a jungle, forest, or undergrowth is contained in the damage circle corresponding to forest fires or tree blowdown it is changed to a forest fire or tree blowdown, respectively. If it is contained in both circles of damage, that circle which contains more than the other dominates in the assessment. If both circles contain the same portion, a random number determines the result.

(d) In general, a fixed percentage of mines is detonated in that portion of a minefield covered by the appropriate circle of damage. Assessment of a minefield results in a new minefield with a reduced mine density.

(e) Towns may be reduced to rubble or burned, but the Nuclear Assessment Model does not distinguish between these outcomes. If more than one half the town is contained in the single damage circle corresponding to towns, it is considered damaged. Casualties are not accounted for by the model as a function of damage to the town.

(4) Creation of an Induced Radiation Hazard Area:

(a) As a function of the soil type, an induced radiation hazard area is defined as being centered at ground zero and extending to a distance at which the radiation 1 hour after burst is 2 rad/hr. This barrier is placed on the barrier/facility file with other information required in a decision to breach.

(b) The radiation barrier record indicates the ground zero coordinates, the radius corresponding to the 2 rad/hr radiation rate, the time of the blast, and two inner radii corresponding to moderate and emergency radiation levels which are expected to exist 1 hour after the blast. The criteria used in defining the inner radii are the following:

1. The moderate risk radius is the radius at which the dose rate expected 1 hour after burst is 20 rad/hr.

2. The emergency risk radius is the radius at which the dose rate expected 1 hour after burst is 50 rad/hr.

(5) Radiation Assessment Scheduling:

(a) Radiation assessment scheduling is a continuous process for those units receiving a radiation dose which is initialized with their first exposure. The first exposure may be one of two types:

1. If any portion of a unit is contained in any of the circles of damage corresponding to delayed personnel casualties, that unit is scheduled for a future assessment due to the delayed effects of incident radiation. The number of personnel to be assessed is determined for each posture as is done in the unit assessment, and the assessment time is determined by a uniform random number between 1 and 4 hours from the time of blast. The following damage radii are considered:

a. Exposed personnel, delayed casualties.

b. Personnel in open foxholes, delayed casualties.

c. Personnel in earth shelters, delayed casualties.

d. Personnel in APCs, delayed casualties.

e. Personnel in tanks, delayed casualties.

2. If any portion of a unit lies within the circle defined by the 2 rad/hr radius of induced radiation, that unit is scheduled for a future assessment due to the effects of induced radiation. Such units may be within the circle due to their movement into the region or due to their failure to move out of the region following the blast. The assessment is scheduled for the time the unit is to leave the area or for 1 hour from the time of the last assessment, whichever occurs first.

(b) At the appropriate time the unit is assessed in one of two ways:

1. Personnel casualties and suppressions calculated at the time of blast are subtracted from the Unit Status File. A subsequent event for each unit is scheduled in order to return suppressed personnel to active status. The time of the subsequent event is determined by selecting a uniform random number between limiting times outlined in FM 101-31-1 (Reference 1).

2. Units in induced radiation areas are allowed to accumulate radiation doses. Every hour, or when the unit leaves the area, the three radiation circles defined on the barrier file are overlayed on the unit to determine the percentage of personnel receiving each of the dose levels. As soon as any portion of a unit accumulates a total dose in excess of 50 rads, that unit is scheduled a future assessment, at which time the appropriate number of personnel will be suppressed or subtracted from the Unit Status File. Numbers of suppressions, casualties, and the assessment time are again determined by selecting random numbers between limiting values outlined in FM 101-31-1.

b. DIVWAG Model Interface:

(1) DSL:

(a) A nuclear fire event is initiated with a DSL FIRE order of the following forms:

STAY UNTIL 010530.
FIRE ON 0139000-0242000
IMPACT RADIUS 200 MUNITION TYPE NZK3
NUMBER OF ROUNDS 1
HEIGHT OF BURST 3.

or:

STAY UNTIL 010530.
FIRE ON 0139000-0242000
IMPACT RADIUS 10 MUNITION TYPE DXY2
NUMBER OF ROUNDS 1.

(b) The first DSL FIRE order is interpreted as follows:

1. At the time of the FIRE order (e.g., 010530) the round is in State of Readiness I (i.e., maximum readiness). The model will add appropriate delay time and flight time to determine when the round actually reaches ground zero.

2. The coordinates of desired ground zero (DGZ) are specified after FIRE ON (e.g., 0139000-0242000).

3. The desired height of burst for only those weapons which allow such a specification is entered in meters after IMPACT RADIUS (e.g., 200). If the weapon's fuze allows only preset height of burst options, the IMPACT RADIUS entry is ignored.

4. Following MUNITION TYPE are four characters:

a. The first character must be N, which identifies the munition type as nuclear.

b. The second character identifies the munition-weapon system to be employed.

c. The third character specifies the fuze option.

d. The fourth character specifies the yield option.

5. The NUMBER OF VOLLEYS modifier is not allowed in a nuclear FIRE order. The number following NUMBER OF ROUNDS must be 1.

6. HEIGHT OF BURST is an optional modifier which must be included in a FIRE order when the munition fuze allows only preset height of burst options. The modifier is not required when the fuze allows specification of the desired height of burst following IMPACT RADIUS. The number following HEIGHT OF BURST must be exactly as defined for the specific munition type in the data preparation.

(c) The second DSL FIRE order is used for atomic demolition munitions (ADM). It is interpreted as follows:

1. At the time of the FIRE order (e.g., 010530) the round is in State of Readiness I. The model will add the appropriate delay time.

2. The coordinates of actual ground zero (AGZ) are specified after FIRE ON (e.g., 0139000-0242000).

3. The actual depth of burst is entered as a positive number after IMPACT RADIUS (e.g., 10, indicating that the weapon is buried at a depth of 10 meters).

4. Following MUNITION TYPE are four characters:

a. The character D identifies the munition type as ADM.

b. The second character identifies the munition to be employed.

c. The third character specifies the fuze option.

d. The fourth character specifies the yield option.

5. The number following NUMBER OF ROUNDS must be 1.

6. The optional HEIGHT OF BURST modifier cannot be used.

(2) Engineer Model:

(a) A part of the execution of the nuclear FIRE order is to request a search of the appropriate area for a list of obstacles/facilities to be assessed. The Engineer Model returns an array of storage locations of such obstacle/facility records.

(b) Each record is examined individually to determine if the corresponding obstacle/facility is affected by the nuclear weapon's effects. If the obstacle/facility is destroyed the appropriate word in the record is changed to reflect the destruction, and the record is replaced. If the obstacle/facility is changed (e.g., tree blowdown) the appropriate word in the record is changed to reflect the destruction of the original obstacle/facility and a new record is created to establish the existence of a new obstacle. If an obstacle is created (e.g., induced radiation area) a new record is created to establish its existence and provided to the obstacle/facility file.

(3) Ground Combat Model. A nuclear fire event is scheduled such that ground combat is interrupted. The weapon is fired as scheduled, casualties are assessed, and ground combat continues.

(4) Intelligence and Control Model. During the search for units to assess, a search is also made for sensor locations. Each sensor is assessed by using the equipment damage radius associated with the item code index.

(5) Movement Model:

(a) If during a MOVE event a unit encounters an induced radiation barrier a decision must be made as to whether the unit should attempt to cross. Parameters available to aid in such a determination are the following:

1. Actual ground zero.

2. Time of last barrier decay update.

3. Three dosage rate radii which will exist 1 hour following the last barrier decay update:

a. 2 rad/hr.

b. 20 rad/hr.

c. 50 rad/hr.

4. Unit radiation history record.

5. Unit safety level.

(b) The unit safety level is a new parameter to be carried on the Unit Status File. There are three allowable levels of troop safety.

1. Negligible. Personnel in a unit with a negligible risk level should not attempt to enter a radiation hazard area if the duration of their activities in the area will result in a total dose greater than 50 rads. Such troops are completely safe from militarily significant effects. Negligible risk should not be exceeded unless significant advantage will be gained.

2. Moderate. A moderate risk from exposure to nuclear radiation occurs either when an individual or a unit has a significant radiation exposure history, but has not yet shown signs of radiation sickness, or when a contemplated single dose is sufficiently high that exposure, in conjunction with previous exposures, would constitute a significant radiation exposure history. Personnel in a unit with a moderate risk level should not attempt to enter a radiation hazard area if the duration of their activities in the area will result in a total dose greater than 200 rads. A moderate risk should not be exceeded if troops are expected to operate at full efficiency after exposure.

3. Emergency. For emergency risk conditions the anticipated effect on troops may be a few casualties; however, casualties should never be extensive enough to neutralize a unit. An emergency risk from exposure to nuclear radiation occurs when a planned single dose, in conjunction with previous exposures, would exceed or approach the threshold for combat ineffectiveness. Personnel in a unit with an emergency risk level should not attempt to enter a radiation hazard area if the duration of their activities in the area will result in a total dose greater than 500 rads. An emergency risk should be accepted only when absolutely necessary.

(c) A decision as to action to occur as a result of the encounter is simulated in the Movement Model.

3. SUBMODEL SPECIFICATIONS:

a. General. The five phases of the assessment methodology discussed in Model Design are treated by four major submodels within the Nuclear Assessment Model. Barrier/facility assessment and creation of induced radiation hazard areas are combined into a single submodel. Each of the other phases is treated by a distinct submodel.

b. Location of Ground Zero:

(1) General. In conventional artillery fires, weapon effects are obtained by firing many rounds and allowing the inherent delivery errors to place the rounds randomly throughout the target area. In nuclear fires, weapon effects are dependent on the delivery errors of a single round. Figure 11-2 illustrates the importance in nuclear fires of considering elliptical dispersion patterns as well as the fire unit's location relative to the target unit in assessing damage to a rectangular area. Depicted in this figure is the damage resulting from a detonation at the extreme edge of the dispersion pattern for identical weapon systems attacking a target from different directions. In (a) the fire unit is located such that the largest component of the weapon system's aiming error is parallel to the smallest dimension of the target unit. In (b) the fire unit is located such that the largest component of the weapon system's aiming error is parallel to the largest dimension of the target unit. The resulting damage differs for these cases by a factor of about 4.

(2) Horizontal Dispersion. Assuming an elliptical dispersion pattern, a conditional actual ground zero is calculated using the range and deflection standard deviations, the coordinates of desired ground zero, and the weapon and target locations.

(a) The range and deflection errors are determined by generating a normal deviate from a uniform deviate using the Hasting's approximation of Equation 11-1:

$$X = a\left\{\eta - \left(\frac{2.515517 + 0.802853\eta + 0.010328\eta^2}{1 + 1.432788\eta + 0.189269\eta^2 + 0.001308\eta^3}\right)\right\} \qquad (11\text{-}1)$$

where:

X is the normal deviate and η is given by Equation 11-2:

$$\eta = \sqrt{\ln\left(1 / (0.5 - q)^2\right)} \qquad (11\text{-}2)$$

In Equation 11-2 q is a uniform random number between zero and one. The variable a in Equation 11-1 takes on the sign of (0.5 - q).

(b) Two uniform random numbers are used to generate two normal deviates, X_r and X_d, corresponding to range and deflection. The errors in range and deflection, Δr and Δd, are found from Equation 11-3:

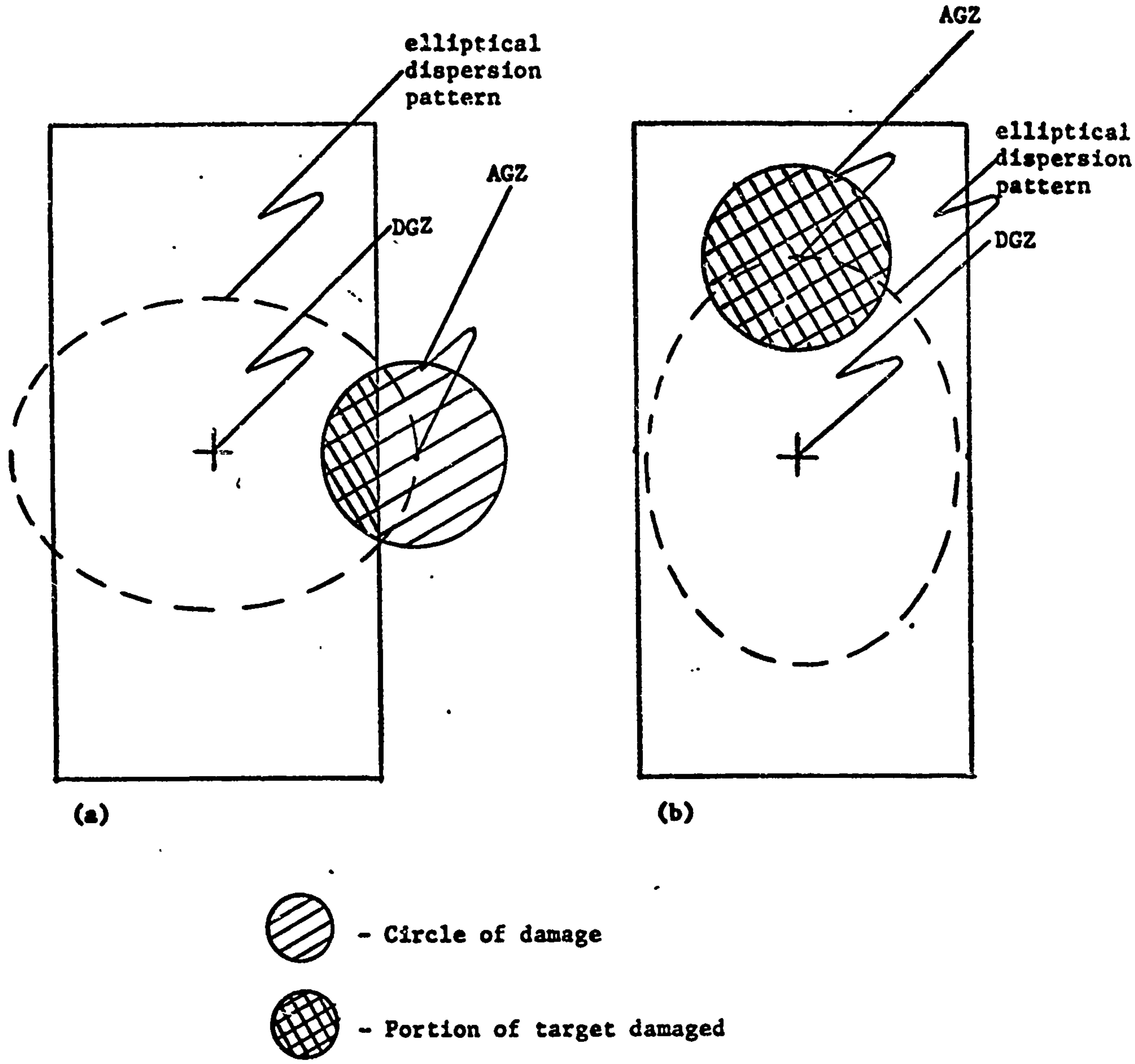


Figure 11-2. Effect of Ell_ptical Dispersion Pattern on Damage Assessment

$$\Delta r = \sigma_r X_r \tag{11-3a}$$

$$\Delta d = \sigma_d X_d \tag{11-3b}$$

where σ_r and σ_d are the range and deflection standard deviations associated with the weapon system.

(3) Vertical Dispersion. Using the desired height of burst, H_o, and the height of burst standard deviation, σ_H, the actual height of burst H is calculated using Equation 11-4:

$$H = H_o + \sigma_H X_H \tag{11-4}$$

where X_H is another solution of Equation 11-1 using a new random number.

(4) Range Error Modification. The horizontal delivery errors of Equation 11-3 are conditional on the error associated with the height of burst. Figure 11-3 depicts this dependence, which is limited to range. In this figure R' represents the detonation range, which includes the error Δr of Equation 11-3a. H_o and H represent the desired and actual heights of burst, and θ is the angle of the incoming round. R is the actual detonation range and is related to R' by Equation 11-5:

$$R = R' + \delta r = R' - \frac{H - H_o}{\tan\theta} \tag{11-5}$$

(5) Determination of Actual Ground Zero. The total range error, ΔR, is found by summing Δr from Equation 11-3a and δr defined by Equation 11-5. Actual ground zero is resolved into x and y coordinates using Equation 11-6:

$$x = x_o + \frac{\Delta R(x_o - x') - \Delta d(y_o - y')}{D} \tag{11-6a}$$

$$y = y_o + \frac{\Delta R(y_o - y') + \Delta d(x_o - x')}{D} \tag{11-6b}$$

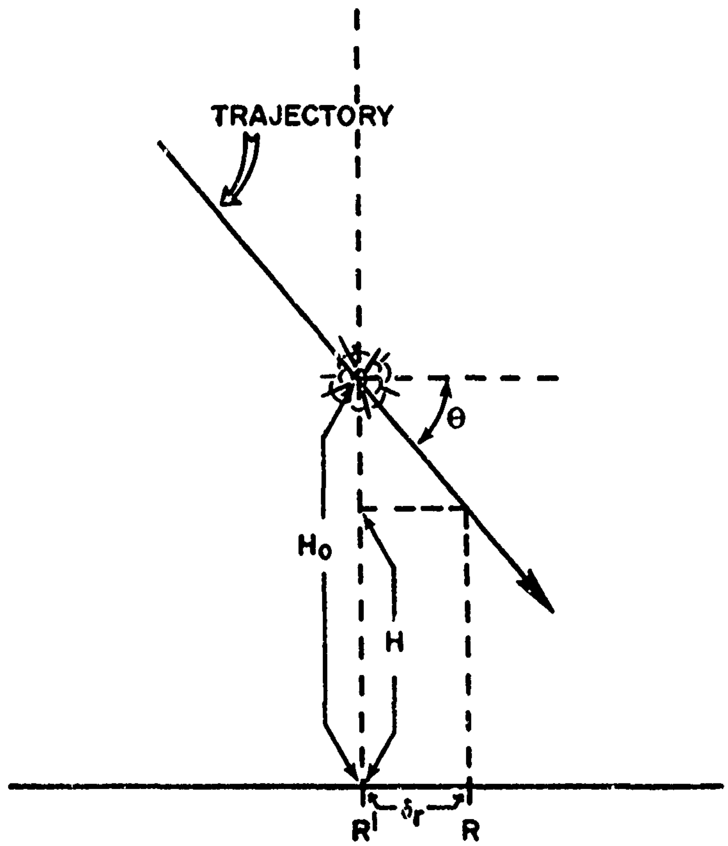


Figure 11-3. Effect of Error in Height of Burst on Error in Range

where x_0, y_0, and x', y' are the coordinates of desired ground zero and the fire unit, respectively, and D is the horizontal distance from the fire unit to desired ground zero. Δd is defined in Equation 11-3b, and x, y are the coordinates of actual ground zero.

(6) Damage Radius Determination. After the actual height of burst, H, is determined by Equation 11-4 the damage radii are calculated before initiating the assessment process. Damage radii are input in the form of a radius of damage against each equiment type, each personnel posture, and each barrier/facility type for each desired yield at each of four heights of burst. The Nuclear Assessment Model assumes the nuclear weapon will function at the rated yield. The actual height of burst is then compared with the four input heights of burst for the specified yield for each damage category. If the actual height of burst falls within the range of input values a simple linear interpolation is used to determine the damage radius against each target category. If the actual height of burst falls outside the range of input values a linear extrapolation is used to determine the damage radius against each target category. If the actual height of burst is less than or equal to zero a check is made to see if the fuze specification allows for an impact detonation. If it does not the round is considered a dud, and there is no assessment.

c. Assessment of Units:

(1) General. The configuration of units and distribution of equipment and personnel within the unit bands, the distribution of protected and unprotected personnel, and the distribution of unprotected personnel among various postures are discussed in Chapter 5. The concept of all distributions presented therein applies to the Nuclear Assessment Model, although the numerical distribtuions may be different. The warned condition within the Nuclear Assessment Model implies receipt of a nuclear strike warning (STRIKWARN) message. The three postures for unprotected personnel are slightly different for the Nuclear Assessment Model as discussed in Paragraph 2, and data are required for both a nuclear environment and a nonnuclear environment. The nuclear environment is assumed to commence immediately following the initial employment of nuclear weapons.

(2) Determination of Area in Common between a Circle and Each Unit Band. The calculation of area in common between rectangular unit bands and circular damage areas is fundamental to the calculation of number of losses. The general methodology outlined here is applied for each unit-oriented damage radius against each band of every friendly and enemy unit, which is covered entirely or partially by the largest such damage pattern. The coordinates of the four corners of a band of a unit as presented in Equations 5-13, the coordinates of actual ground zero, and the radius of damage are required for a solution, which can be divided into five major cases with various subcases. Each of the possible cases will be shown in general figures. Figure 11-4 shows the various parts of a circle used in the following discussion. For

convenience a segment is denoted by the notation usually reserved for the minor arc which bounds it; i.e., the segment shown in Figure 11-4 would be denoted by $\overline{AB}$. Notice that the sector CDE can be decomposed into two areas, CDE and $\overline{DE}$. This allows the area of the segment to be calculated as area of segment, $\overline{CD}$ = {area of sector CDE} - {area of triangle CDE}. In the following equations A(·) is used to mean area of (·).

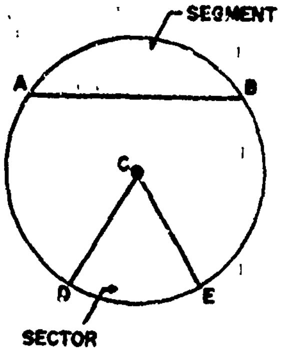


Figure 11-4. Various Parts of a Circle

(a) Case I. One of the rectangle's vertices inside the circle. Figure 11-5 shows the two subcases of Case I.

1. Case Ia, area in common is given by the formula:

$$\text{AREACOM} = A(AV_1B) + A(\overline{AB}).$$

2. Case Ib, area in common is given by the formula:

$$\text{AREACOM} = A(V_1V_2V_3V_4) + A(\overline{AB}) + A(\overline{CD}) - A(AV_4B) - A(CDV_2V_3).$$

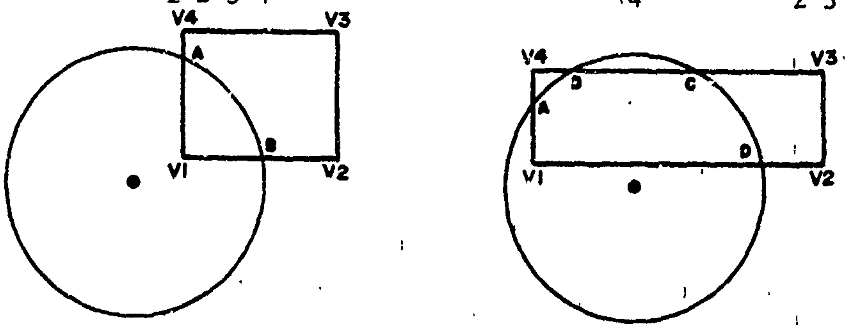


Figure 11-5. Geometry of Subcases Ia and Ib

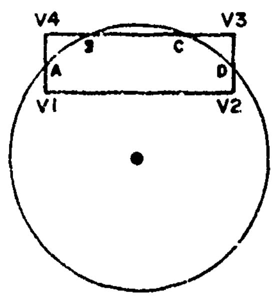
(b) Case II. Two of the rectangle's vertices inside the circle. Figure 11-6 shows the two subcases of Case II.

1. Case IIa. The area in common is calculated by the formula:

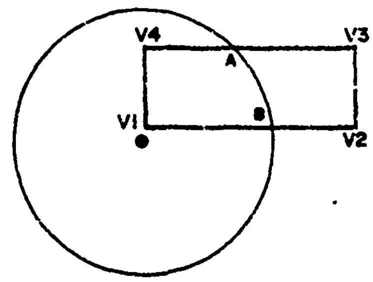
$$\text{AREACOM} = A(V_1V_2V_3V_4) + A(\overline{AB}) + A(\overline{CD}) - A(AV_4B) - A(CV_3D).$$

2. Case IIb. The area in common is calculated by the formula:

$$\text{AREACOM} = A(V_1V_2V_3V_4) + A(\overline{AB}) - A(ABV_2V_3)$$



Case IIa



Case IIb

Figure 11-6. Geometry of Subcases IIa and IIb

(c) Case III. Three of the rectangle's vertices inside the circle. Figure 11-7 shows the geometry of Case III. The area in common is calculated by the formula:

$$\text{AREACOM} = A(V_1V_2V_3V_4) + A(\overline{AB}) - A(AV_4B).$$

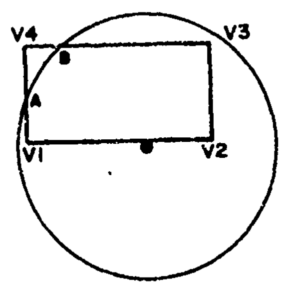


Figure 11-7. Geometry of Case III

(d) Case IV. All four of the rectangle's vertices inside the circle. Figure 11-8 shows the geometry of Case IV. The area in common is given by the formula:

$$\text{AREACOM} = A(V_1V_2V_3V_4)$$

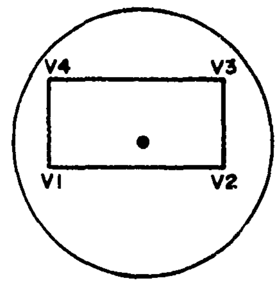


Figure 11-8. Geometry of Case IV

(e) Case V. None of the rectangle's vertices inside the circle. Figure 11-9 shows the geometry of the various subcases of Case V.

1. Case Va. The area in common is calculated by the formula:

$$\text{AREACOM} = A(\overline{AB})$$

2. Case Vb. The area in common is calculated by the formula:

$$\text{AREACOM} = A(\text{circie}) - A(\overline{AB})$$

3. Case Vc. The area in common is calculated by the formula:

$$\text{AREACOM} = A(\text{circle}) - A(\overline{AB}) - A(\overline{CD})$$

4. Case Vd. The area in common is calculated by the formula:

$$\text{AREACOM} = A(\overline{AB}) - A(\overline{CD})$$

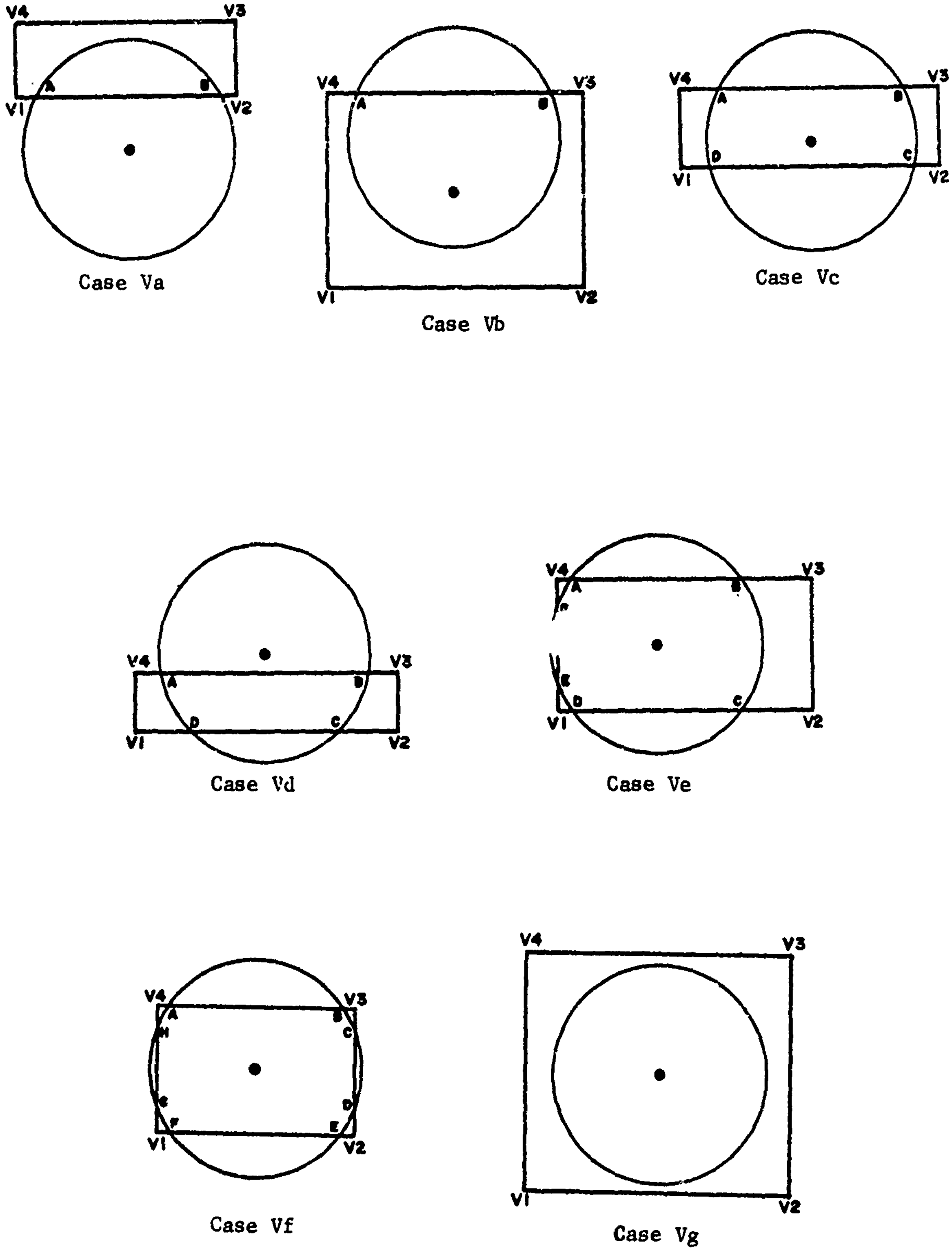


Figure 11-9. Geometry of Case V

5. Case Ve. The area in common is calculated by the formula:

$$AREACOM = A(circle) - A(\overline{AB}) - A(\overline{CD}) - A(\overline{EF})$$

6. Case Vf. The area in common is calculated by the formula:

$$AREACOM = A(circle) - A(\overline{AB}) - A(\overline{CD}) - A(\overline{EF}) - A(\overline{GH})$$

7. Case Vg. The area in common is calculated by the formula:

$$AREACOM = A(circle)$$

(3) Determination of Equipment Losses. Each equipment type item code which is to be included in the assessment is linked to one of the six available damage radii provided for assessment of primary equipment items. Each Red and Blue unit found to be in the damage area corresponding to the largest damage radius is assessed. The assessment involves determining the area in common between each damage radius and each band of the unit.

(a) Initial Primary Equipment. For each of the six damage radii (four damage radii, if the unit is in flight) a check is made to see if the unit has at least one equipment item which is to be assessed using the radius. Only those radii which qualify are considered. Primary equipment losses are then calculated using Equation 11-7:

$$CAS_i^{(I)} = \sum_j N_i \, f_{ij} \, AREACOM_{ij}/A_j \qquad (11\text{-}7)$$

where:

$CAS_i^{(I)}$ = equipment losses of type i

N_i = equipment on hand of type i

f_{ij} = percent of equipment type i in band j

$AREACOM_{ij}$ = area in common between the damage radius against equipment type i and band j

A_j = area of the jth band.

The sum in Equation 11-7 is over all bands in the unit.

(b) Additional Primary Equipment. Each equipment item identified as a tank or an APC or as an item which provides similar protection may also be included in an additional assessment. If the damage radius corresponding to prompt casualties for personnel in the equipment item is larger than the damage radius against the equipment item itself an additional assessment is made. The number of primary equipment items left unmanned as a result of the nuclear fire is calculated by Equation 11-8:

$$CAS_i^{(A)} = \sum_j N_i \, f_{ij} \, AREACOM'_{ij}/A_j \qquad (11\text{-}8)$$

where:

$CAS_i^{(A)}$ = equipment of type i left unmanned

$AREACOM'_{ij}$ = area in common between the damage radius against personnel in equipment type i and band j.

(c) Total Primary Equipment. The equipment losses calculated by Equation 11-8 differ from those calculated by Equation 11-7 in that the equipment is not actually destroyed. Such equipment, however, has been subjected to intense radiation and cannot be considered usable for an extended period of time; therefore, it is considered an equipment casualty. The Nuclear Assessment Model defines the total equipment losses of type i, CAS_i, as all equipment of type i which is destroyed or not usable by Equation 11-9:

$$CAS_i = CAS_i^{(I)} + CAS_i^{(A)} \qquad (11\text{-}9)$$

The value of $CAS_i^{(A)}$ as well as the location of such equipment is provided in the Period Processor output with future retrieval left to gamer discretion.

(d) Secondary Equipment. Once the primary items have been assessed, the secondary losses are computed from the secondary equipment tables using Equation 11-10:

$$CAS_k = \sum_i CAS_i \, d_{ik} \, E_k/N_k \qquad (11\text{-}10)$$

where:

CAS_k = losses of secondary equipment item k

CAS_i = losses of primary equipment item i

d_{ik} = number of secondary items k authorized to primary item i

E_k = secondary item k on hand in unit

N_k = secondary item k authorized in unit.

(4) Determination of Prompt Personnel Losses. Personnel casualties are determined by a two-step process involving different categories of protection. Included in the assessment are personnel protected by equipment items which are destroyed, personnel protected by equipment items which are not destroyed but offer insufficient protection against the incident radiation, and personnel which are not protected by equipment items.

(a) Personnel Protected by Equipment. The number of personnel lost when the equipment providing protection is lost or left unmanned is calculated by Equation 11-11:

$$C_p = \sum_i n_i \, CAS_i \qquad (11\text{-}11)$$

where:

C_p = number of protected personnel casualties

n_i = casualties per equipment item type i.

(b) Personnel Not Protected by Equipment. The number of unprotected personnel in the unit is calculated using Equation 11-12:

$$N_u = N - \sum_i E_i \, m_i \qquad (11\text{-}12)$$

where:

N_u = number of unprotected personnel

E_i = equipment type i on hand in unit

m_i = personnel protected per equipment type i

N = present strength of the unit.

If N_u is greater than zero the number of unprotected personnel casualties is determined by Equation 11-13:

$$C_u = \sum_h \sum_j N_u f_j p_h \, AREACOM_{hj}/A_j \qquad (11\text{-}13)$$

where:

C_u = number of unprotected personnel casualties

f_j = percent of personnel in band j

p_h = percent of personnel in posture h

$AREACOM_{hj}$ = area in common between damage radius against personnel in posture h and band j

(c) Total Casualties. The total personnel casualties, C, is calculated by Equation 11-14:

$$C = C_p + C_u \qquad (11\text{-}14)$$

d. Assessment of Barriers/Facilities. The barrier/facility assessment is a two-step process involving the destruction of existing barriers/facilities and the creation of an induced radiation barrier.

(1) Assessment of Existing Barriers/Facilities. The largest damage radius applicable to barriers/facilities is used to perform a search for candidates for assessment. The assessment methodology is based on the concept of the damage circle covering more than half the barrier/facility. Within the DIVWAG Model barriers and facilities are maintained as line segments. Determination of the 50 percent containment is accomplished by artificially giving the line segment a width of 1 meter to make it compatible with the existing circle/rectangle methodology. The fraction of the line segment contained in the circle can then be expressed by Equation 11-15:

$$F = AREACOM/L \qquad (11\text{-}15)$$

where:

F = the fraction of the line segment within the circle

AREACOM = area in common between the 1-meter-wide rectangle and the circle

L = the length of the line segment (L carries the units of an area: L = (Lm) x (1m) = Lm^2)

(a) Bridges. If F is greater than one half, the bridge is destroyed.

(b) Towns. If F is greater than one half, the town in destroyed.

(c) Jungles, Forests, Undergrowth. Separate values are calculated for fires, F_f, and blowdown, F_b, if such radii are provided.

1. If F_f is greater than one half and F_b is less than one half, the forest is burned.

2. If F_f is less than one half and F_b is greater than one half, the forest is blown down.

3. If both are greater than one half and F_f is greater than F_b, the forest is burned.

4. If both are greater than one half and F_f is less than F_b, the forest is blown down.

5. If both are greater than one half and F_f is equal to F_b, a random number decides the resulting damage. If the number is greater than one half, the forest is burned; otherwise, it is blown down.

(d) Minefields. If F is greater than one half, the minefield density is reduced one level. Minefield density levels are discussed in Chapter 8.

(2) Creation of Induced Radiation Barriers. An area of induced radiation remains centered at ground zero following a nuclear detonation. Information regarding the area is placed on the barrier file to prevent troop movement through the area. The Nuclear Assessment Model provides three radii corresponding to negligible, moderate, and emergency nuclear radiation risk levels to troops. The radiation rates corresponding to these levels are 2 rad/hr, 20 rad/hr, and 50 rad/hr, respectively. Also provided is the future time at which these radiation rates are projected to exist. Data from TM 23-200 (Reference 3) indicate that the radiation rate 1 hour after blast can be approximately related to the slant range by Equation 11-16:

$$\text{Rate} \cong a\, e^{-br} \qquad (11\text{-}16)$$

where:

Rate = radiation rate (rad/hr) 1 hour after blast

r = slant range

a,b = parameters dependent on soil type and yield.

(a) Equation 11-16 can be solved for r for each of the three desired rates using Equation 11-17:

$$r_i = -\frac{1}{b}\ln\left(\frac{\text{Rate}_i}{a}\right) \qquad (11\text{-}17)$$

where:

Rate_1 = 2 rad/hr

Rate_2 = 20 rad/hr

Rate_3 = 50 rad/hr.

(b) The ground ranges, R_i, corresponding to the slant ranges, r_i, of Equation 11-17 are found using Equation 11-18:

$$R_i = \sqrt{r_i^2 - H^2} \qquad (11\text{-}18)$$

where H was defined in Equation 11-4.

e. Radiation Assessment and Scheduling:

(1) General. The Nuclear Assessment Model provides for three phases of radiation assessment and scheduling. Included in the assessment are those delayed casualties and/or suppressions resulting from the incident radiation, casualties and/or suppressions resulting from a unit's movement through an induced radiation barrier, and continuous updating of the radiation barrier size as it decays.

(2) Delayed Casualties. From FM 101-31-1 (Reference 1) the existing damage radii for delayed personnel casualties are based on a dose of 650 rad. The biological response to such a dose as well as other doses is provided in Figure 11-10. All radiation assessment methodology is based on data in this table.

Biological Response to Nuclear Radiation.

Estimated exposure range (rads)	*Initial symptoms*	*Onset of symptoms*	*Incapacitation*	*Hospitalization*	*Duration of hospitalization*	*Final disposition*
50 to 200 ...	None to transient mild headache.	Approximately 6 hours after exposure.	None to slight decrease in ability to conduct normal duties.	Hospitalization required for less than 5 percent in upper part of exposure range.	45 to 60 days in upper part of range.	Duty. No deaths anticipated.
200 to 500 ...	Headaches, nausea, and vomiting; malaise. Symptoms not relieved by antimetics in upper part of exposure range.	Approximately 4 to 6 hours after exposure.	Can perform routine tasks. Sustained combat or comparable activities hampered for period of 6 to 20 hours.	Hospitalization required for 90 percent of exposed personnel in this range. Hospitalization follows latent period of 17 to 21 days' duration.	60 to 90 days ..	Some deaths anticipated; probably less than 5 percent at lower part of range, increasing toward upper end.
500 to 1,000 ..	Severe and prolonged nausea and vomiting; difficult to cure. Diarrhea and fever early in upper part of exposure range.	Approximately 1 to 4 hours after exposure.	Can perform only simple, routine tasks. Significant incapacitation in upper part of exposure range; lasts more than 24 hours.	Hospitalization required for 100 percent of exposed personnel. Latent period short, 7 to 10 days in lower range to none in upper range.	90 to 120 days for those surviving.	Approximately 50-percent deaths at lower part of range, increasing toward upper end; all deaths occurring within 45 days.
Greater than 1,000.	Severe vomiting, diarrhea, and prostration.	Less than 1 hour after exposure.	Progressive incapacitation, following an early capability for intermittent heroic response.	Hospitalization required for 100 percent of exposed personnel. No latent period.	3 to 30 days ...	100-percent deaths occurring within 30 days.

Figure 11-10. Biological Response to Nuclear Radiation (Reference 1)

(a) At the time of the fire event the percent of personnel within the unit which will become casualties and/or be suppressed is determined using Equation 11-19:

$$C_d = \frac{1}{N}\left(\sum_h \sum_j N_u f_j p_h (AREACOM'_{hj} - AREACOM_{hj})/A_j\right)$$

$$+ \sum_j N_i f_{ij} (AREACOM'_{ij} - AREACOM_{ij})/A_j \qquad (11\text{-}19)$$

where:

C_d = percent of unit which will become casualties and/or be suppressed

N = present strength of unit

N_u = number of unprotected personnel (Equation 11-12)

f_j = percent of personnel in band j

p_h = percent of personnel in posture h

$AREACOM'_{hj}$ = area in common between damage circle for delayed casualties to personnel in posture h and band j

$AREACOM_{hj}$ = area in common between damage circle for prompt casualties to personnel in posture h and band j

A_j = area of band j

N_i = equipment type i on hand

f_{ij} = percent of equipment type i in band j

$AREACOM'_{ij}$ = area in common between damage circle for delayed casualties to personnel in equipment type i and band j

$AREACOM_{ij}$ = area in common between damage circle for prompt casualties to personnel in equipment type i and band j

(b) From Figure 11-10 the onset of symptoms due to a 650 rad dose is expected to occur from 1 to 4 hours after exposure. A uniform random number between 60 and 240 is used to determine the number of minutes after the blast at which casualties are expected to occur. For this dose the table indicates approximately 50 percent deaths, with more than a 24-hour period of incapacitation. An assessment record is maintained carrying this information, and a future assessment event is scheduled.

(c) At the time of the future assessment, C_d from Equation 11-19 is applied to the present strength of the unit. Fifty percent of the resulting number of personnel are considered casualties, remaining personnel being suppressed. Another event is scheduled for 24 hours from the current time.

(d) At the time of the last assessment 0.5 C_d is applied to the present strength to determine the number of suppressed personnel returning to active status.

(3) Radiation Barrier Assessment. Whenever a unit encounters a radiation barrier the Nuclear Assessment Model calculates the dose received by that unit and schedules an assessment event if appropriate. Stationary units are given accumulated doses every hour for as long as they remain in the area. Moving units are given a dose corresponding to the time to cross the barrier. Unit radiation dose histories are maintained for every unit which encounters a radiation area.

(a) Dose rates are determined by overlaying the three barrier radii discussed above on the unit. Personnel in each band which are in the area in common between the band and the 2 rad/hr radius and not in the area in common with the 20 rad/hr radius are given a dose rate of 10 rad/hr. Personnel in each band in the area in common with the 20 rad/hr radius and not in the area in common with the 50 rad/hr radius are given a dose rate of 35 rad/hr. Personnel in each band in the area in common with the 50 rad/hr radius are given a dose rate given by Equation 11-20:

$$\text{Rate} = \frac{1}{2}\left(50 + a\ e^{-bH}\right) \qquad (11\text{-}20)$$

where the second term in parentheses is Equation 11-16 evaluated at ground zero.

(b) Total hourly doses for stationary units are determined by giving the fraction of personnel in the unit receiving each of the three dose rates a dose corresponding to each rate multiplied by 1 hour. The percentage of personnel in the unit receiving each of the three doses is maintained in a history record for possible future accumulation of additional doses.

(c) Total doses for moving units are determined by calculating the areas in common at the time when ground zero is colinear with the unit's leading edge as depicted in Figure 11-11. In this figure d_1, d_2, d_3 are the chords to the 2 rad/hr, 20 rad/hr, and 50 rad/hr circles midway between the circle's radius and the radius of the next smaller circle (or the unit's edge). Dose rates of 10 rad/hr, 35 rad/hr, and the rate given by Equation 11-20 are given to those personnel in the areas labeled A_{10}, A_{35} and A_{50+}. The time to cross through each of the areas is determined by Equation 11-21:

$$t_i = d_i/v \qquad (11\text{-}21)$$

where v is the unit velocity. The percentage of personnel in the unit receiving each of the three doses is maintained as for stationary units.

(d) Doses are accumulated for all units using Equations 11-22:

$$d_1 = d_{1i} + d_{1c} \qquad (11\text{-}22a)$$

$$d_2 = d_{2i} + d_{2c} \qquad (11\text{-}22b)$$

$$d_3 = d_{3i} + d_{3c} \qquad (11\text{-}22c)$$

$$\begin{aligned} p_1 = {} & p_{1i}(1 - \sum_k p_{kc}) + p_{1c} (1 - \sum_k p_{ki}) \\ & + p_{1i}\, p_{1c} + p_{2i} (1 - \sum_k p_{kc}) \\ & + p_{2c} (1 - \sum_k p_{ki}) \\ & + 1/2 (p_{1i}\, p_{2c} + p_{1c}\, p_{2i}) \end{aligned} \qquad (11\text{-}22d)$$

$$\begin{aligned} p_2 = {} & 1/2 (p_{1i}\, p_{2c} + p_{1c}\, p_{2i}) \\ & + p_{3i} (1 - \sum_k p_{kc}) + p_{3c} (1 - \sum_k p_{ki}) \\ & + p_{2i}\, p_{2c} + p_{1i}\, p_{3c} + p_{1c}\, p_{3i} \\ & + 1/2 (p_{2i}\, p_{3c} + p_{2c}\, p_{3i}) \end{aligned} \qquad (11\text{-}22e)$$

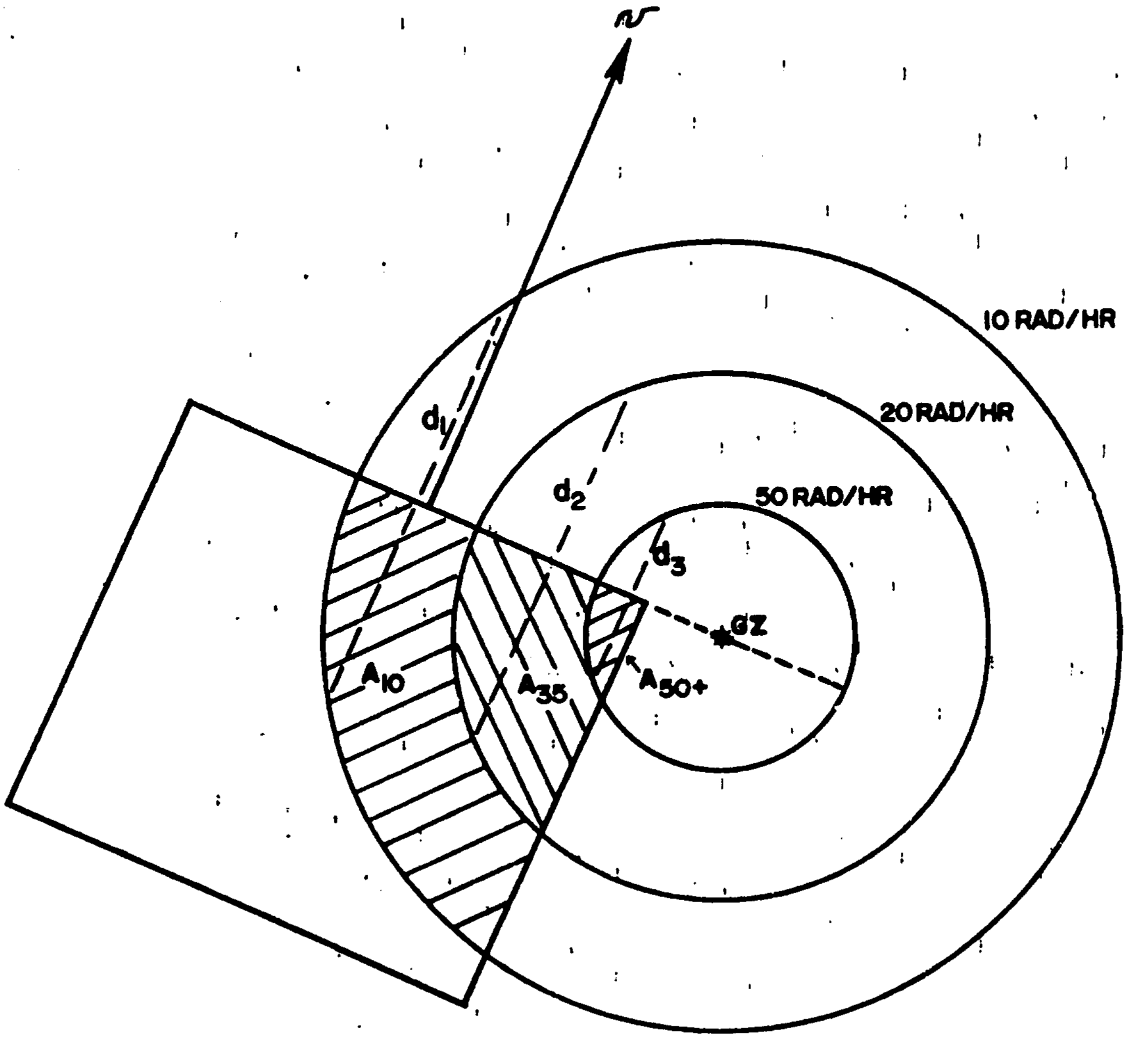


Figure 11-11. Barrier Assessment for a Moving Unit

$$p_3 = 1/2\,(p_{2i}\,p_{3c} + p_{2c}\,p_{3i})$$

$$+ p_{3i}\,p_{3c} \qquad (11\text{-}22f)$$

where:

d_1, d_2, d_3 = new dose levels ($d_3 > d_2 > d_1$)

p_1, p_2, p_3 = percent of the unit in each new dose level

d_{1i}, d_{2i}, d_{3i} = previous unit dose levels ($d_{3i} > d_{2i} > d_{1i}$)

p_{1i}, p_{2i}, p_{3i} = percent of the unit in each previous dose level

d_{1c}, d_{2c}, d_{3c} = dose levels from current assessment ($d_{3c} > d_{2c} > d_{1c}$)

p_{1c}, p_{2c}, p_{3c} = percent of the unit in each current dose level

(e) Equations 11-22 are intended to distribute the personnel having received a dose among the new dose levels such that the following conditions are satisfied:

1. Personnel having received no dose as the result of several assessments of the unit are not included in any of the dose levels.

2. Personnel having received an accumulated dose less than $1/2(d_1 + d_2)$ are included in level 1 (the lowest total dose).

3. Personnel having received an accumulated dose greater than $1/2(d_1 + d_2)$ but less than $1/2(d_2 + d_3)$ are included in level 2 (the intermediate total dose).

4. Personnel having received an accumulated dose greater than $1/2(d_2 + d_3)$ are included in level 3 (the highest total dose).

(f) For a unit with no previous radiation history the following is used in lieu of Equations 11-22:

- $p_1 = p_{1c}$
- $p_2 = p_{2c}$
- $p_3 = p_{3c}$

- $d_1 = d_{1c}$
- $d_2 = d_{2c}$
- $d_3 = d_{3c}$

(g) As soon as some percentage of a unit's personnel accumulate a dose in excess of 50 rads an assessment event is scheduled. These assessments are processed the same as delayed casualties with all event times determined by random numbers between the limiting times set forth in Figure 11-10.

(4) Radiation Barrier Update. Whenever a barrier is used in an assessment, or once an hour, whichever comes first, the barrier radii are reduced to reflect the decay. The time rate of decay of the radiation rate can be expressed by Equation 11-23:

$$\text{Rate}(t) = \text{Rate}\,(t=0)t^{-1.2} \qquad (11\text{-}23)$$

Equation 11-23 is equated with Equation 11-16 to find the new slant ranges corresponding to the three dose rates. The result is similar to Equation 11-17 and is presented in Equation 11-24:

$$r_i = -\frac{1}{b}\ln\left(\frac{\text{Rate}_i t^{-1.2}}{a}\right) \qquad (11\text{-}24)$$

4. REFERENCES:

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